

SMALL SPACECRAFT TECHNOLOGY INITIATIVE (SSTI)

"Progress and Technology Achievement Report"
14 October 1996

NASA Headquarters Contract #NASW-4945

INTRODUCTION AND OVERVIEW

This is the fourth report of a series of semi-annual reports that describe the technology areas being advanced under this contract and the progress achieved to date.

The most significant technical event this period was the successful completion of the Lewis spacecraft in 2 years (contract award date was June 1994). In August of 1996 we held a program-wide Technology Workshop which covered all aspects of the Lewis payload. A copy of the Workshop proceedings is attached.

Numerous papers and media articles featuring Lewis technologies were published in the most recent 6 month period. Some of these are listed below:

1. Design News, September 9, 1996, "Big Science from a Small Satellite."
2. Laser-Focus World, August 1996, "Hyperspectral Imager will view many colors of Earth."
3. SPIE Volume 2808, 1996, "EUV, X-Ray and Gamma Ray Instrumentations for Astronomy VII, "The Diffuse EUV Spectrometer UCB."
4. 20th International Symposium on Space Technology and Science, GIFU, Japan, May 19-25, 1996, SSTI-Lewis Spacecraft Program.
5. IEEE: Proceedings, "Hyperspectral Imaging Payload for the NASA Small Satellite Technology Initiative Program," 1996.
6. SSTI-Lewis Better, Faster and Cheaper Guidance, Navigation and Control Subsystem. AIAA/USU Small Satellite Conference 1996, Utah State University.
7. SPIE Symposium, September 1996, "Lewis Hyperspectral Imager Payload Development."

Significant progress was made in demonstrating new technologies in spacecraft dynamics testing. In this period we completed Lewis spacecraft vibration, pyroshock and "tap" testing. In the process of readying Lewis for launch, we accomplished the following:

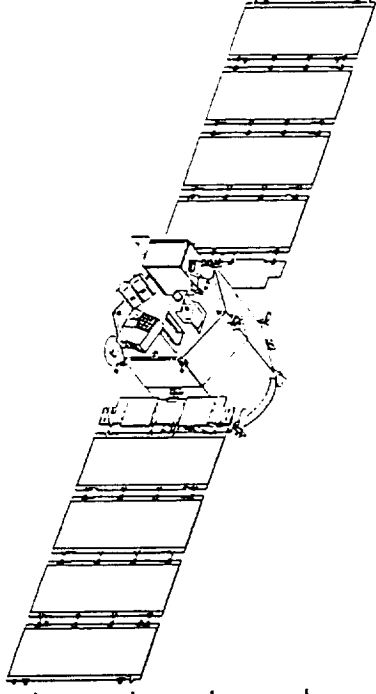
- **Graphite/viscoelastic damping tiles** to eliminate launch load and on-orbit jitter concerns on the payload instrument. Tile technology will see immediate insertion on the EOS program to alleviate launch vibro-acoustics concerns.
- **Graphite/VEM damped hat section** used as a retrofit to solve a critical launch load vibration problem. We foresee this being an effective tool when one wants to simultaneously add significant stiffness and damping to a structure.
- **A new vibroacoustic analysis methodology** using the full spacecraft Nastran model was pioneered on SSTI. The method was proven and is now being employed on EOS and other programs.
- **Automated response limited vibration testing** was employed for the first time to provide realistic test levels to the main optical payload (HSI) without causing damage due to over-test. We anticipate this technique will be used on most upcoming NASA programs.
- **Test-tuning dynamic models using local tap test data** and a portable analyzer. We demonstrated the ability to measure frequencies and damping on major portions of a spacecraft in one and a half days, including setup. Previous modal-survey techniques would have taken far longer. The test-verified frequencies and damping reduce the uncertainty inherent in load cycle results.
- **Test methodologies for adaptive vibration controllers** on structures. The lessons learned are having an impact on all our future cryocooler products.

The spacecraft completed many major test milestones during this period including:

- Thermal Vacuum and Thermal Cycling (4 cycles).
- 3-Axis Random Vibration.
- Pyro-Shock testing with live ordnance.
- 4 complete integrated system tests.

- Completion of Hyperspectral Imager Thermal Vacuum and Vibration tests and delivery to System I&T.

The spacecraft was placed in storage in mid-June 1996 and is now undergoing final integrated system testing in preparation for final build and shipment to VAFB for launch.



WORKSHOP

AUGUST 8/9, 1996

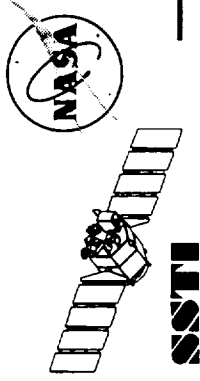


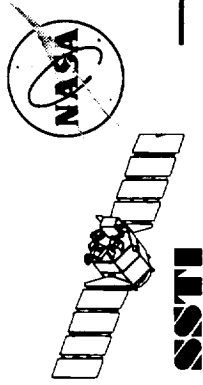
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*Provided as a separate package to Government only



Plenary Session

8:00-9:30

8 August 1996

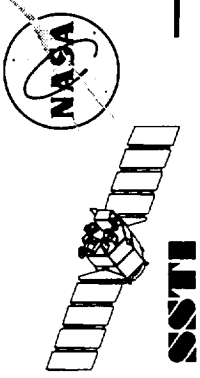
Workshop Overview

DAY 1 August 8, 1996

8:00 am	9:30	11:45	1:00 pm	5:00
Session 1 Plenary E2 Auditorium	Session 2 Internal M2/2105	L U N C H		Session 4 Independent Technology Demonstrations E2 Auditorium
	Session 3 Spacecraft Technologies E2 Auditorium			

DAY 2 August 9, 1996

8:00 am	11:45	1:00 pm	3:30	4:30
Session 5 Independent Technology Demonstrations <i>Park Patio Cafe</i>	L U N C H			Session 8 Workshop Adjournment <i>E2 Auditorium</i>
Session 6 Advanced Instrument Technologies <i>E2 Auditorium</i>				



Plenary Session Agenda



Time (Minutes)

Welcome/Facility Overview

15

- Session Chairperson Introductions/Changes

15

- Session Overview/Changes

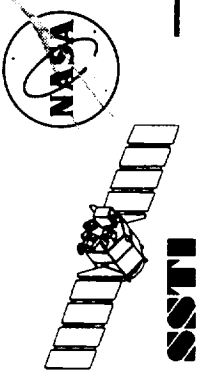
- Government session procedures/badging

- Sam Venneri of NASA Headquarters Keynote Address

30

- Spacecraft/Mission Overview

30



Session 2 Government Session



- Closed session limited to TRW/Government representatives per contractual requirements
- Badge required for entry into building M2
- Badges available to government employees only with appropriate identification
- Meet at E2 lobby East entrance immediately following conclusion of Plenary session to walk as a group to building M2

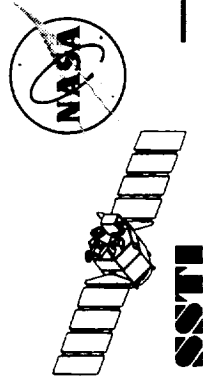


August 8 – Session 3 Spacecraft Technologies



9:30 - 12:00 – E2 Auditorium – Chair: Dick Woods

	<u>Speaker</u>	<u>Time</u>
• GFRP Wrapped Tank	Joe Lewis	9:30–9:55
• NiH2 CPV Battery Cells	Bob Tobias	9:55–10:20
• Lightweight GFRP Structures	Al Barrett	10:20–10:45
• WFOV Star Tracker and Earth Sensor	Paul Parry	10:45–11:10
• R3000 Processor	Peter McShane	11:10–11:35
• Solid State Recorder	Derek Au	11:35–12:00

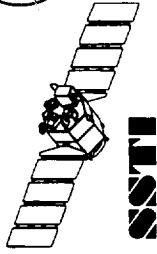


August 8 – Day 1 Session 4 Independent Technology Demonstrations

TRW

1:00-5:00 – E2 Auditorium – Chair: Roger Avant

	<u>Speaker</u>	<u>Time</u>
• Miniaturized WFOV Star Tracker	Paul Parry/ Al Gauthier	1:00-1:30
• High efficiency Solar Cells	George Vendura/ Ed Gaddy	1:30-2:30
• GPS Attitude Determination	Frank Bauer	2:30-3:00
• Launch Loads Measurement System	Kirsten Kirkman	3:00-3:30
• Magnetically Suspended Reaction Wheel	Marty Beck	3:30-4:00
• Autonomous Orbit Control	Jim Wertz	4:00-4:30
• High Ratio Data Compression	Warner Miller	4:30-5:00

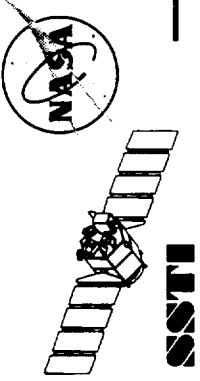


August 9 – Session 5 Independent Technology Demonstrations– Continued



8:00-11:45 – Park Patio Cafe – Chair: Dick Woods

	<u>Speaker</u>	<u>Time</u>
• Metal Matrix Heat Strap	Gordon Casto	8:00-8:30
• Radiation Counter	Judy Shinn	8:30-9:00
• Clouds and Features Editing	Harry Benz	9:00-9:30
• Advanced RISC RH-32 Packaging Experiment	Rudy Almeida	9:30-10:00
• Photovoltaic Regulator Kit Expt.	Tony Baez	10:00-10:30
• MIMO Attitude Control	Peiman Maghami	10:30-11:00
• Goddard Experiment Module	Phil Luers	11:00-11:30

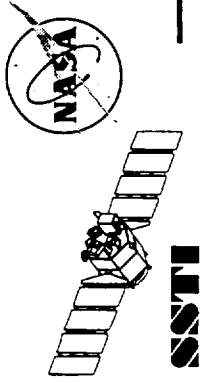


August 9 – Day 2 – Session 6 Advanced Instrument Technologies



8:00 - 11:45 – E2 Auditorium – Chair: Jay Pearlman

	<u>Speaker</u>	<u>Time</u>
• Hyperspectral Imager	Jay Marmo	8:00-9:00
• Pulse Tube Cryocooler	Manny Tward	9:00-9:45
• Linear Etalon Imaging Spectral Array	Don Jennings/ Dennis Reuter	9:45-10:30
• Optical Pointing Assembly	Marty Beck	10:30-11:00
• Ultraviolet Cosmic Background Spectrometer	Stuart Bowyer	11:00-11:45



August 9 – Session 7 Experimental Procedures



1:00 – 3:30 – E2 Auditorium – Chair: Jay Pearlman

	<u>Speaker</u>	<u>Time</u>
• Planning and Operations	Jim Sarina	1:00-1:45
• Archive Data Processing and Interpretation	Kern Witcher	1:45-2:45
• Mission Tasking Plans	Stephanie Sandor	2:45-3:30

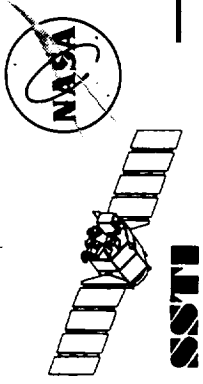


SSTI

TRW



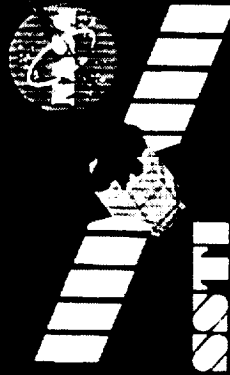
SSTI/Lewis Overview



SSTI Program Objectives

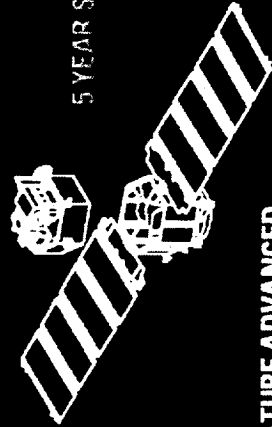


- Reduce Cost and Schedule of Civil Space Missions
- Produce more accessible results
 - Education
 - Science
 - Commercial
- Transition government and industry technology to the civil space sector
 - SDIO
 - Industry research and development
 - Government laboratories and centers



TRW SSTI Mission Overview

OVER 25 SPACECRAFT AND PAYLOAD TECHNOLOGIES DEMONSTRATED



MATURE ADVANCED TECHNOLOGIES INTEGRATED INTO SPACECRAFT BUS

SEPARATE PAYLOAD AND TECHNOLOGY DEMONSTRATION MODULE

SSTI INSTRUMENTS:

- **HYPER SPECTRAL IMAGER (HSI)**
 - 384 SPECTRAL CHANNELS, 0.4 TO 2.5 μm
 - RADIOMETRIC ACCURACY: 6% HYPER SPECTRAL, 16% PAN
 - GROUND SAMPLE DISTANCE: 5 M PANCHROMATIC, 30 M HYPER SPECTRAL
- LINEAR ETALON IMAGING SPECTRAL ARRAY (PLANETARY TECHNOLOGY)
- ULTRAVIOLET COSMIC BACKGROUND

523 KM CIRCULAR
SUN-SYNCHRONOUS ORBIT
(97.0 DEG INCLINATION)

- TRW (CHANTILLY, VA)
- ORBITAL OPERATIONS
 - MISSION DATA ARCHIVE AND DISTRIBUTION

- NASA GODDARD, MD
- LEISA DATA PROCESSING
 - DEMONSTRATION
 - RESULTS ANALYSIS

- NASA LANGLEY, VA
- DEMONSTRATION
 - RESULTS ANALYSIS

- NASA DSN, WOLLOPS
- EARLY ORBIT OPS AND CONTINGENCY

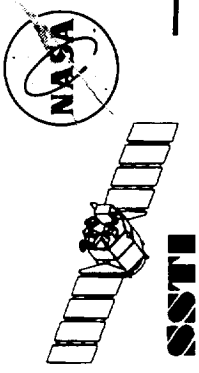
- NASA STENNIS, MS
- HSI DATA CENTER (LEVEL 1 PROCESSING)
 - BACKUP OPERATIONS

- FUTURE HBCU NETWORK
- CLARK ATLANTA
 - HAMPTON UNIV
 - JACKSON ST.
 - MORGAN ST.

- TRW SPACE PARK, CA
- SPACECRAFT BUS
 - HSI PAYLOAD
 - HSI DATA ANALYSIS
 - DEMONSTRATION
 - RESULTS ANALYSIS

UNIV OF ALASKA
(RECEIVE)

- VANDENBURG AFB, CA
- LLV LAUNCH



SSTI-Lewis Overview

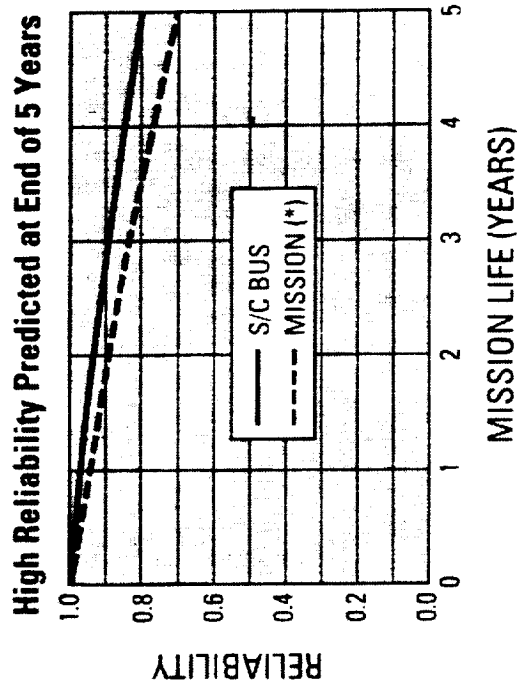


- 5 Year lifetime goal
- Fully redundant subsystem electronics
- 517 km, 97.4° inclination Sun Synchronous Orbit
- 2 year fast-track schedule span
- More than 40 new technologies
- Maximize technology transfer from military to civil space applications

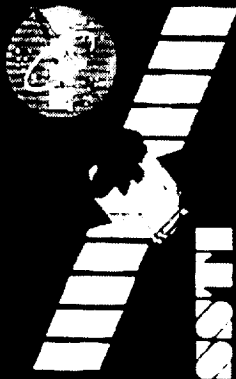
High Reliability Lewis Design

Redundancy Supports High Reliability

- High reliability achieved with fully redundant spacecraft bus avionics
- Redundancy added to HSI payload to support 5-year mission goal
- Concurrent TRW TRWIS III Development lowers HSI risk



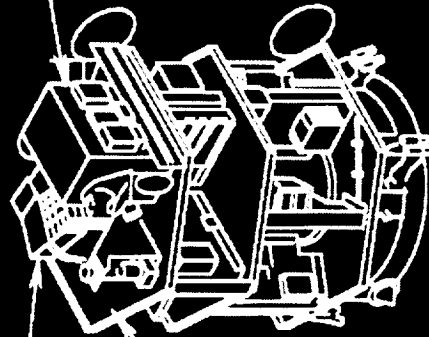
(*) S/C bus + HSI + HSI payload support equipment



SSTI-Lewis System Functional Block Diagram

SPACECRAFT

ULTRA-VIOLET COSMIC BACKGROUND (UCB)



HYPER-SPECTRAL IMAGER (HSI)

LINEAR ETALON IMAGING SPECTRAL ARRAY (LEISA)

KEY SPACECRAFT ELEMENTS

- PAYLOADS & TECH DEMOS
 - PRIMARY INSTRUMENTS
 - SUPPORTING TECHNOLOGIES
 - INDEPENDENT TECH DEMOS
- SPACECRAFT BUS
 - CORE SPACECRAFT FUNCTIONS

SMALL EXPENDABLE LAUNCH VEHICLE (SELV)

SUPPORTING GSS

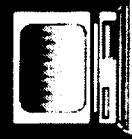


NASA DSN



TX/RX

CHANTILLY, VA



SC OPERATIONS

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NASA STENNIS

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MISSION DATA

NASA STENNIS

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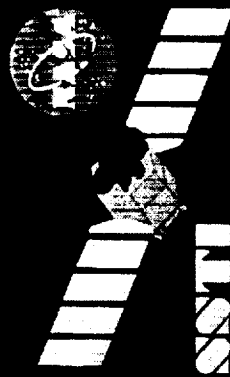
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SC OPERATIONS





Payload Instruments

- Hyper-Spectral Imager (HSI)
 - 384-band, visible/IR earth imaging system, (0.4-2.5 μm wavelength)
 - Fine ground samples: 30 m multispectral, 5 m panchromatic
 - Typical imaging area (384 channels) is 20 x 7.7 km
 - Includes in-flight calibration subsystem (6% for hyperspectral)
 - Broad application data
- Linear Etalon Imaging Spectral Array (LEISA)
 - 256-channel near IR/SWIR earth imaging system
 - Broad-area earth-sensing system; 300 m resolution, 77 km swath
 - Complements HSI
- Ultraviolet Cosmic Background Spectrometer (UCB)
 - Full spectral coverage from 55-105 nm
 - Prime passband coverage of 58.5-95 nm
 - Astrophysical research instrument
 - Measures EUV emission spectra of diffuse space background
 - Will provide data several orders of magnitude more sensitive than prior work



HSI Drives Orbital Conditions

Orbital Parameter	Value	Trades/Drivers
Nominal altitude (relative to mean equatorial radius)	517 km (95.1 min per period, 34.3 to 35.3 min eclipse)	• Revisit time • Ground coverage and max cross-track pointing angle (22 deg) • Ground resolution vs sensor size, mass, and cost • Drag makeup fuel vs insertion fuel
Altitude variation	± 10 km	• Contiguous swath coverage
Eccentricity	0	• Uniform global coverage
Inclination	Sun-synch (97.5 deg)	• Repeatable lighting conditions
Ascending node	10:50 AM $\pm$ 0:20 local time	• Low cloud cover • Favorable lighting conditions

- Conditions acceptable to all other primary payloads and tech demos
- Only additional requirement is inertial, anti-sun pointing mode for UCB

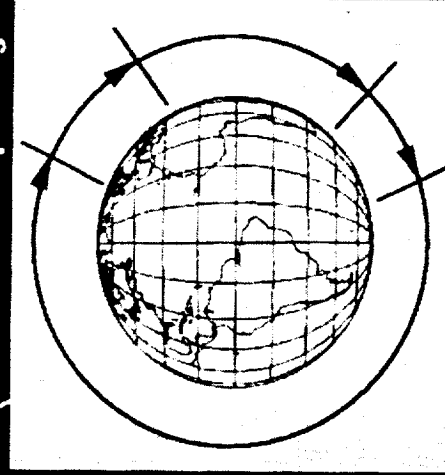


On-Orbit Operations

- HSI and LEISA operate during daylight
 - HSI: $\pm 0-22$ deg roll offset from nadir
 - LEISA: 'look ahead' and sideways nominal operation using pointing mirror
- UCB operates during eclipse
 - Inertial, anti-sun pointed
- Many windows for tech demo operation
 - Background low-rate, low volume
 - No special maneuvers
- Store and forward concept for mission data and historical telemetry
 - Primary ground station at Chantilly, VA
 - Supplemental 'bent pipe' ground station planned at Fairbanks, AK

HSI and LEISA Ops

Maneuver to inertial anti-sun pointing

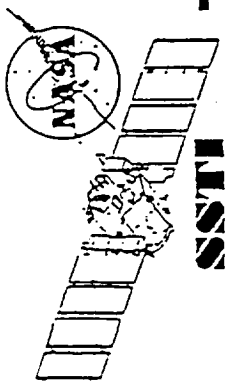


SUN

UCB operation

Maneuver to nadir pointing

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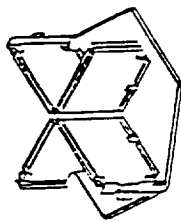
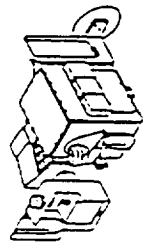


Spacecraft Modularity

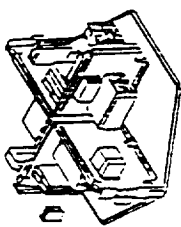


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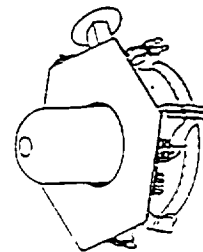
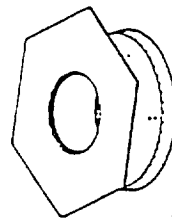
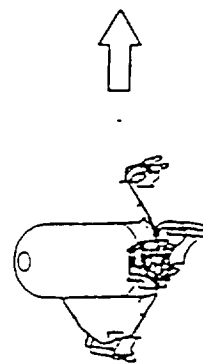
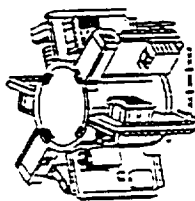
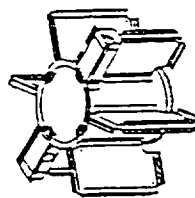
INSTRUMENTS



PAYLOAD
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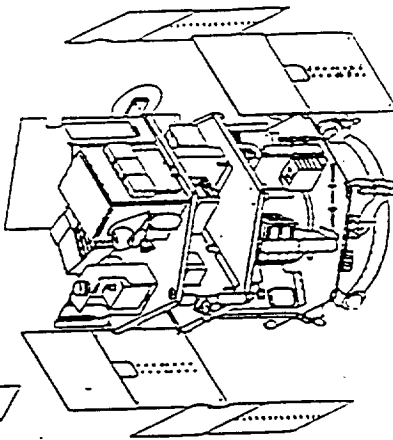
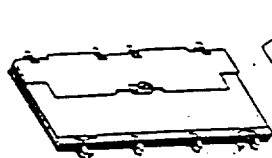
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BATTERY PROPULSION MODULE

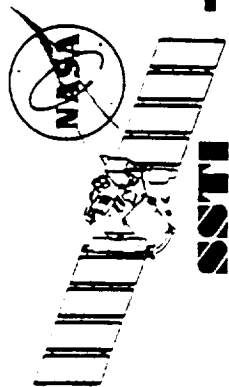
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FINAL
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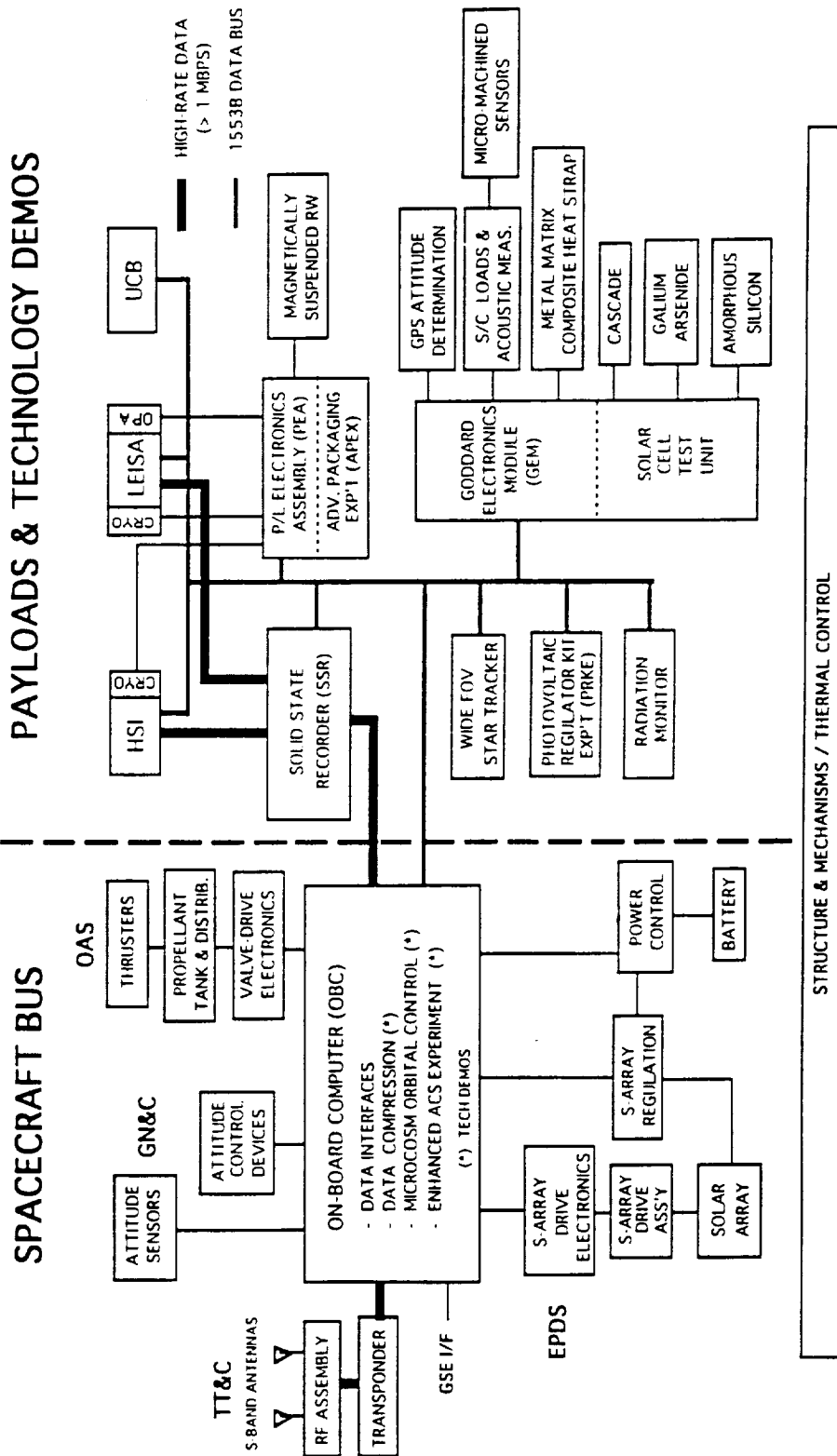


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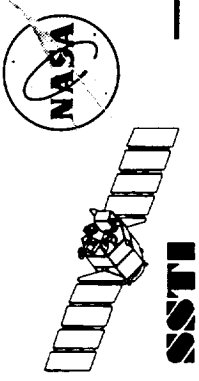
Spacecraft Functional Block Diagram



TRW



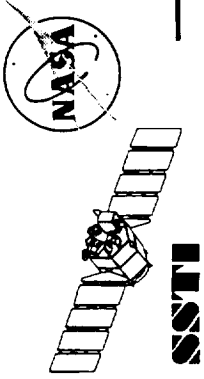
SSTI LEWIS COMPLETE - 6/11/96



Session 2

Internal Session

Separate handout provided to Government only

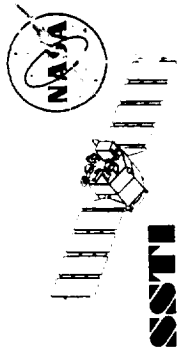


August 8 – Session 3 Spacecraft Technologies



9:30 - 12:00 – E2 Auditorium – Chair: Dick Woods

	<u>Speaker</u>	<u>Time</u>
• GFRP Wrapped Tank	Joe Lewis	9:30–9:55
• NiH2 CPV Battery Cells	Bob Tobias	9:55–10:20
• Lightweight GFRP Structures	Al Barrett	10:20–10:45
• WFOV Star Tracker and Earth Sensor	Paul Parry	10:45–11:10
• R3000 Processor	Peter McShane	11:10–11:35
• Solid State Recorder	Derek Au	11:35–12:00



TRW

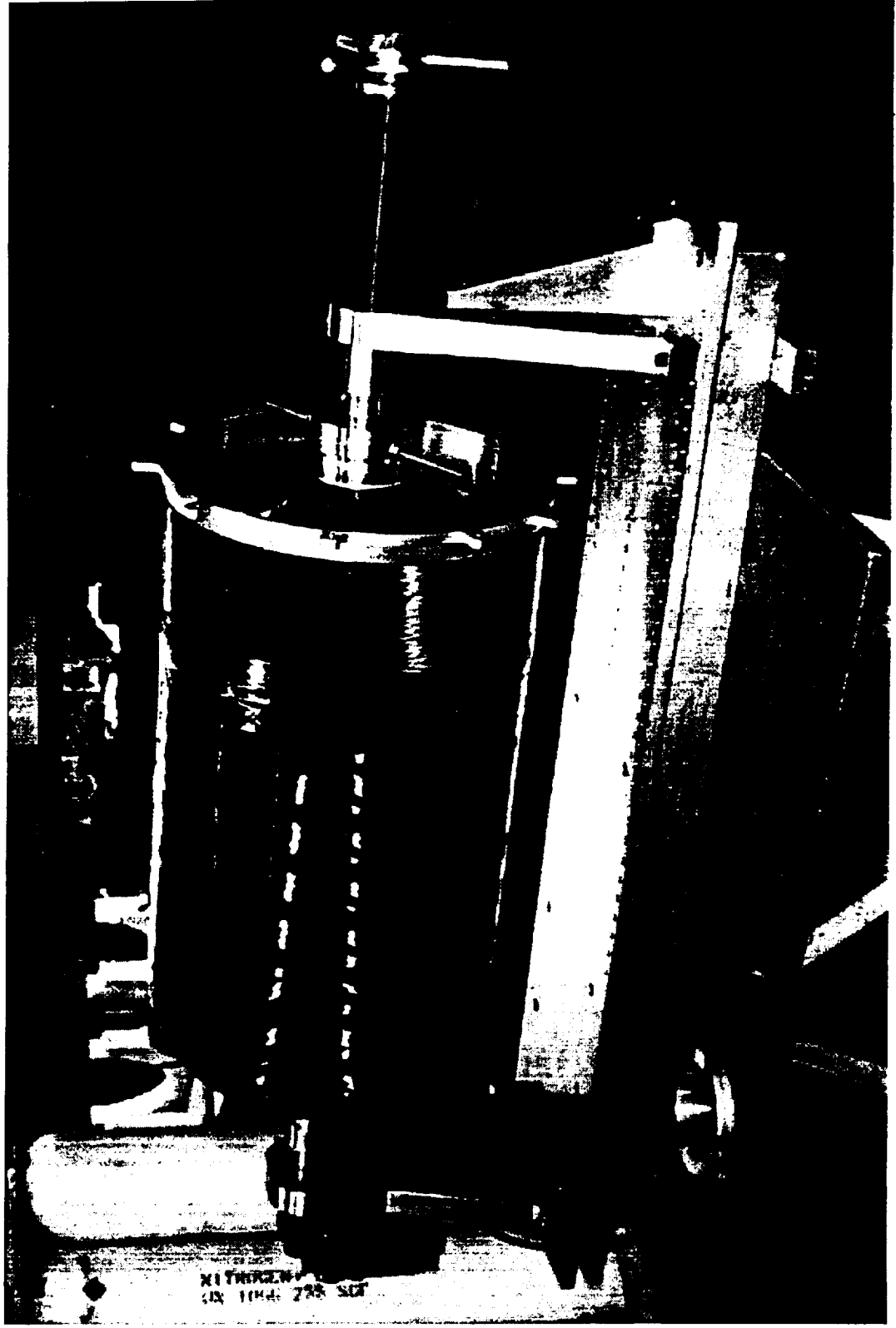


OAS PROPELLANT TANK

J.C. Lewis
8 August 1996

AB600 Propellant Tank

TRW

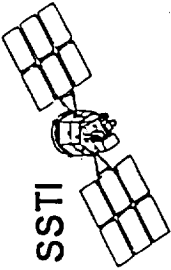


AB600 Propellant Tank

Forward End



O1M 94.089.005

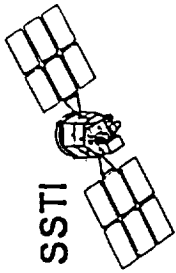


OAS PROPELLANT TANK QUALIFICATION TEST RESULTS

DESCRIPTION

- **MATERIALS:** 0.010-INCH-THICK 6061 SEAMLESS ALUMINUM LINER (MINIMUM) OVERWRAPPED WITH T-1000 GB GRAPHITE/EPOXY COMPOSITE, SKIRT IS IM-6/3501-6 GRAPHITE/EPOXY WITH A 7075-T7351 ALUMINUM MOUNTING RING
- **SIZE:** 17-INCH DIAMETER BY 34-INCH LENGTH
- **SHAPE:** CYLINDRICAL WITH ESSENTIALLY ELLIPSOIDAL HEADS
- **PRESSURES:** MAX. DESIGN PRESSURE = 500 PSID, PROOF = 625 PSID, BURST $\geq$ 750 PSID
- **MAXIMUM WEIGHT:** 15 LBm
- **EXPULSION:** SINGLE INLET/OUTLET BOSS USING PROPELLANT SETTLING (SURFACE-TENSION-TYPE PROPELLANT MANAGEMENT DEVICE PREVENTS GAS INGESTION)
- **LOAD:** 232 LBm OF HYDRAZINE (MAXIMUM)
332 LBm of NITROGEN TETROXIDE (MAXIMUM)

J.C.LEWIS

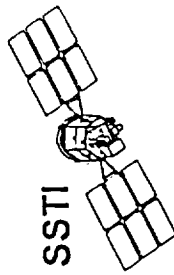


OAS PROPELLANT TANK QUALIFICATION TEST RESULTS

HERITAGE

- ERIIS BI-PROPELLANT TANKS
 - FOUR HAVE FLOWN - ALL SUCCESSFULLY
 - GRAPHITE/EPOXY OVERWRAP WITH 0.020-INCH-THICK ALUMINUM LINERS
 - 4.8-INCH DIAMETER BY 13.8-INCH LENGTH
 - 1000-PSID MAXIMUM DESIGN PRESSURE, 4000-PSID BURST PRESSURE
- PEGASUS HYDRAZINE TANK
 - TWO HAVE FLOWN - BOTH SUCCESSFULLY
 - GRAPHITE/EPOXY OVERWRAP WITH 0.065-INCH-MINIMUM-THICKNESS 6061 ALUMINUM LINERS

J.C.LEWIS



OAS PROPELLANT TANK QUALIFICATION TEST RESULTS

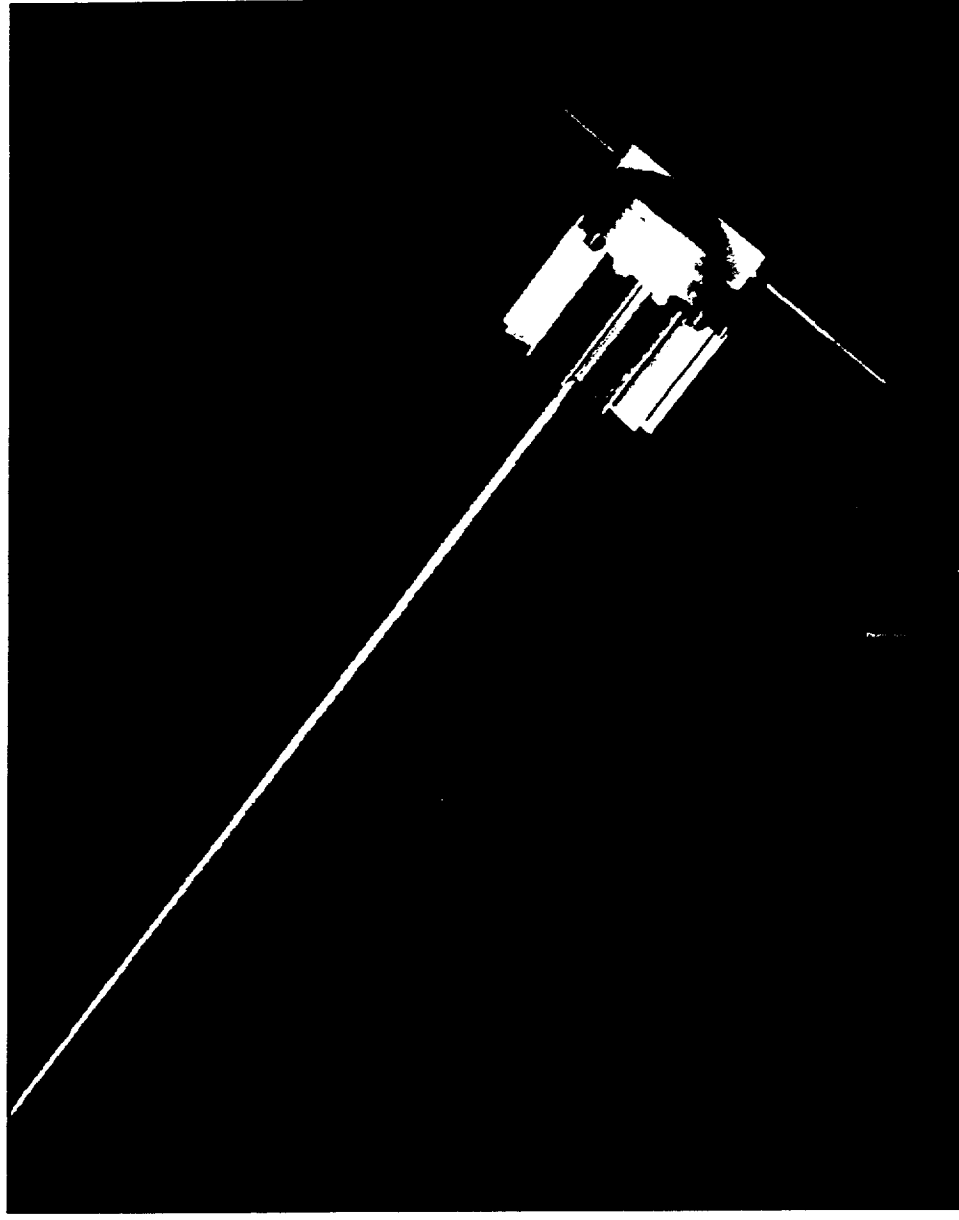
HERITAGE (CONT'D.)

- PEGASUS HYDRAZINE TANK (CONT'D.)
 - 19.7-INCH DIAMETER BY 23.9-INCH LENGTH
 - 464-PSID MAXIMUM DESIGN PRESSURE, 696-PSID MINIMUM BURST PRESSURE
- AB 600 PROPELLANT TANK
 - SSTI TANK IDENTICAL TO AB 600 QUALIFICATION UNIT
 - TWO DEVELOPMENT TANKS BUILT AND SUCCESSFULLY TESTED TO DATE - ONE DVT TANK HAD 0.010 INCH THICK LINER

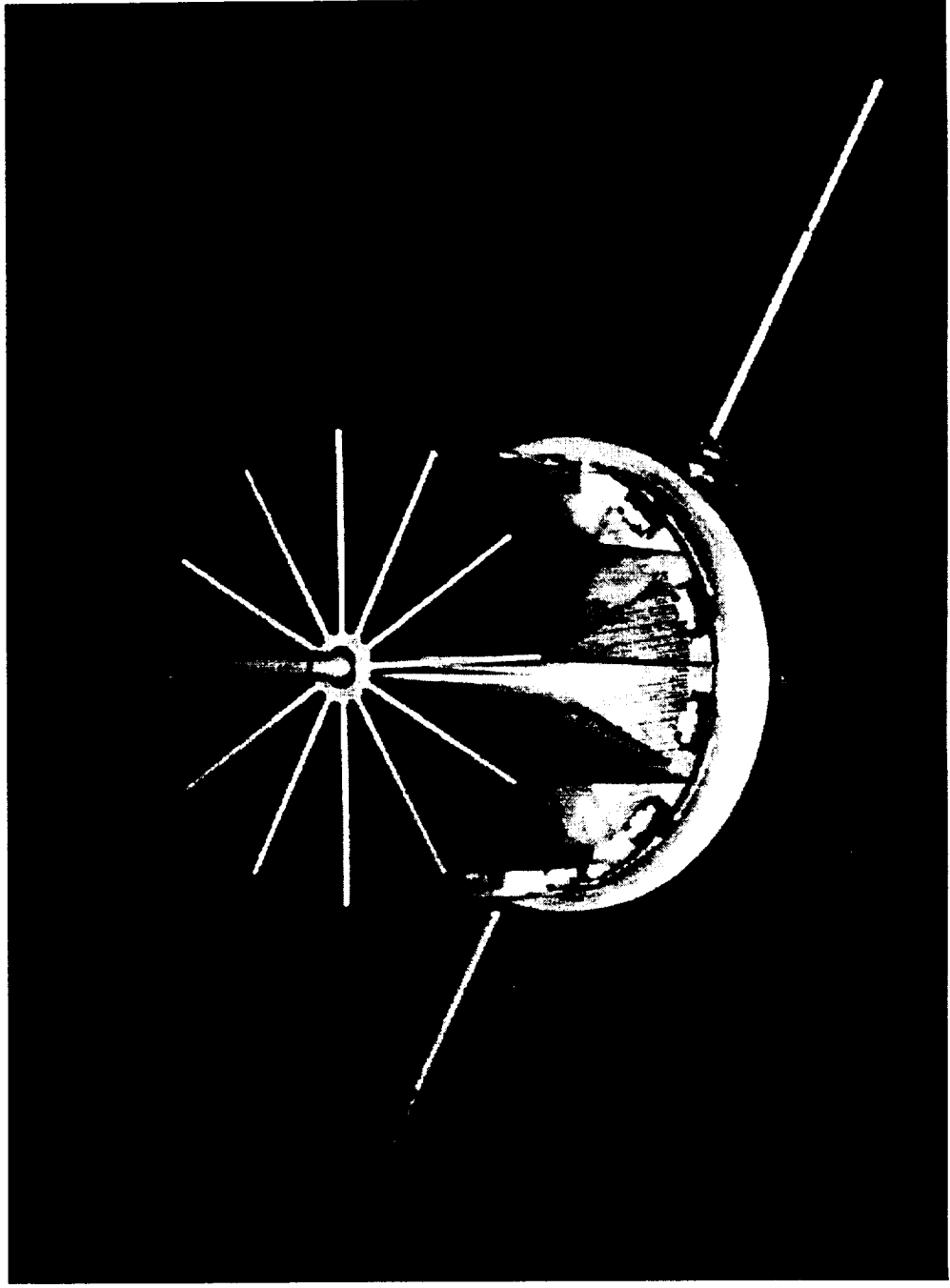
J.C.LEWIS

AB600 Propellant Tank

Outlet CAP/PMD Assembly



AB600 Propellant Tank Outlet CAP/PMD Assembly

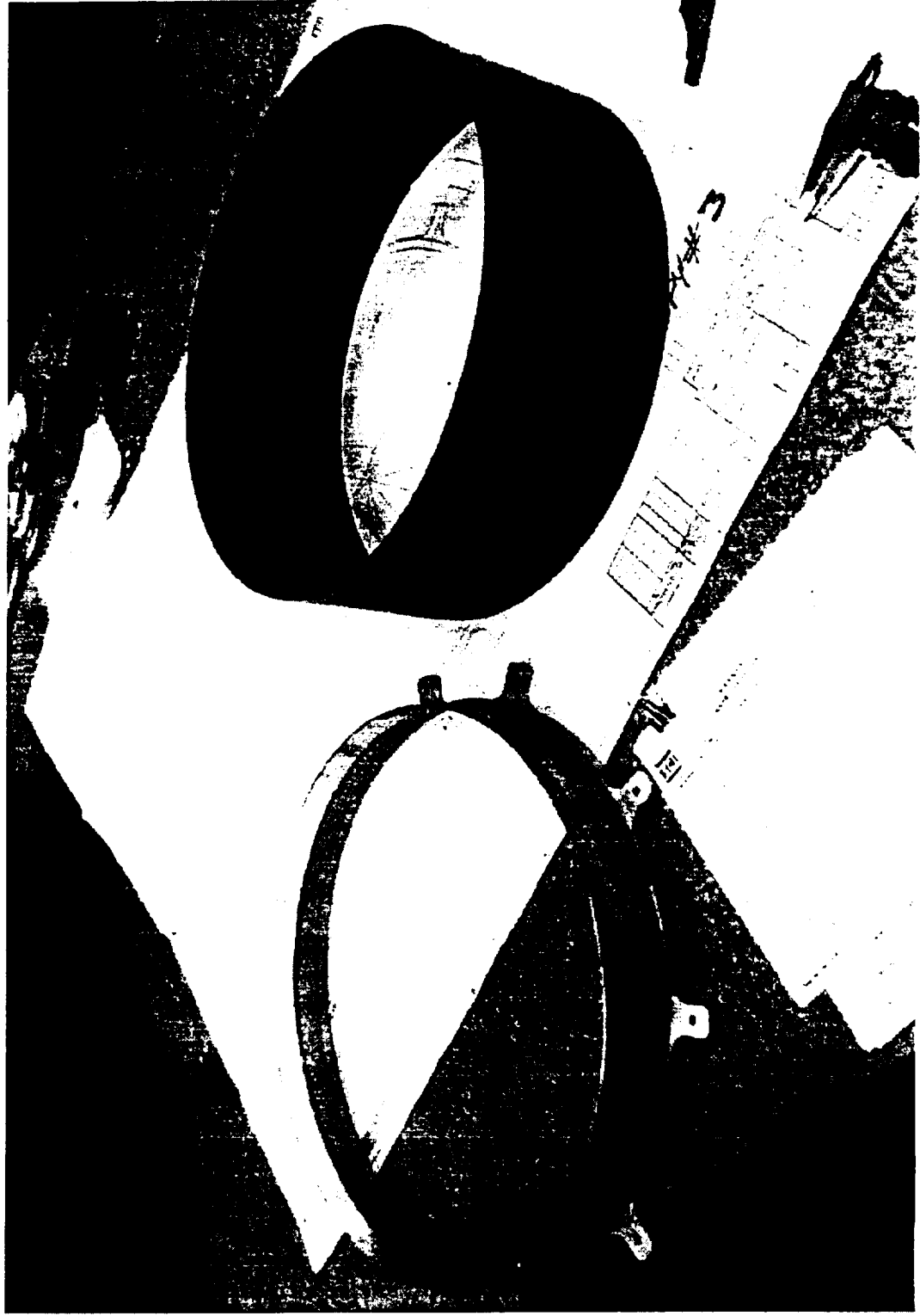


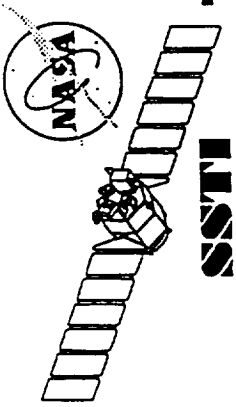
AB600 Propellant Tank PMD Installation



AB600 Propellant Tank

Graphite/Epoxy Skirt and 7075-T7351 Mounting Ring

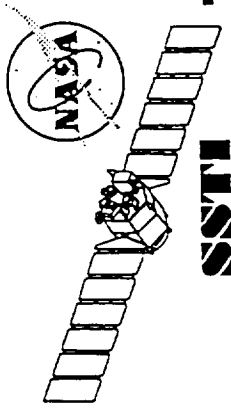




TRW

SSTI BATTERY

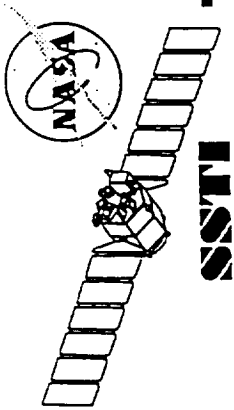
8 AUGUST 1996
R.F. TOBIAS



INTRODUCTION

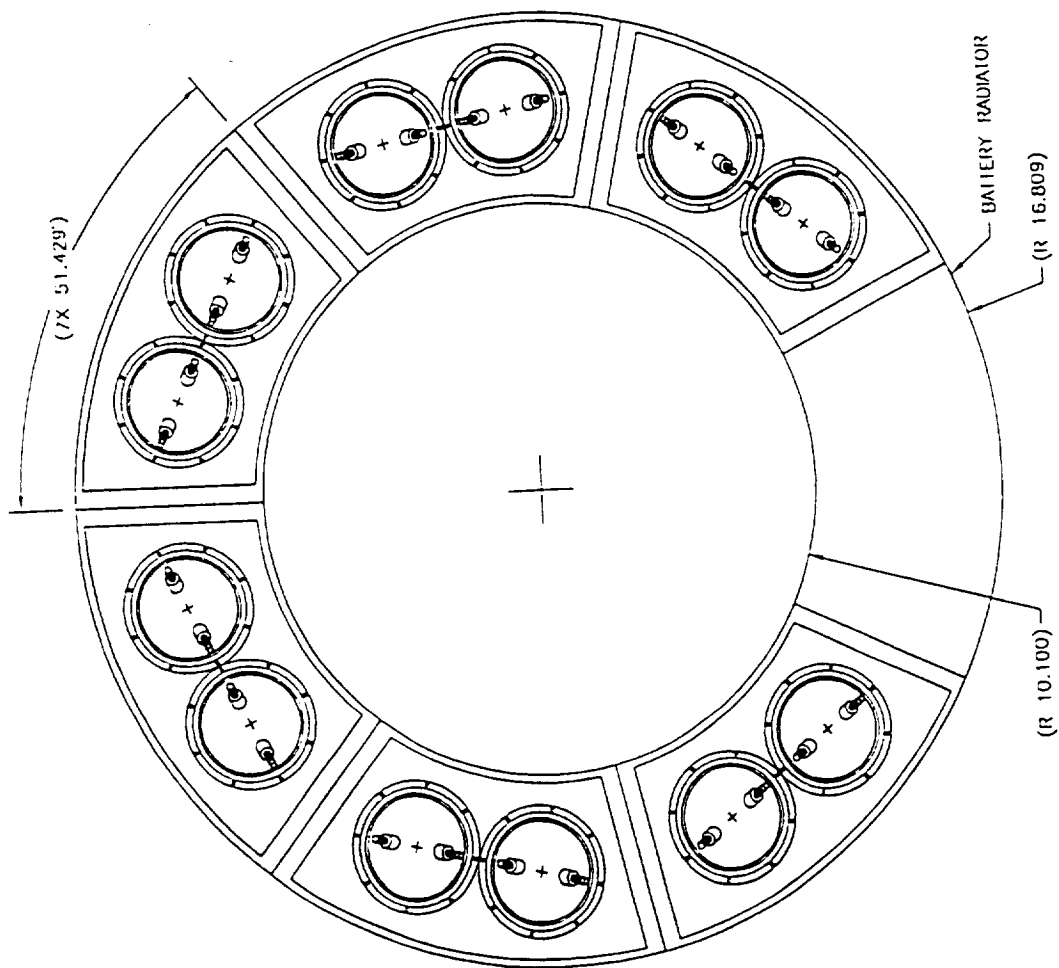


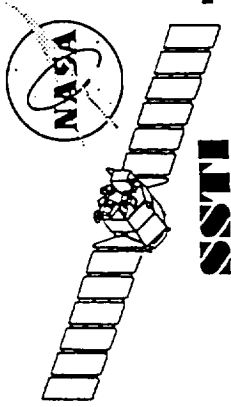
- BATTERY IS NiH₂, 2-CELL COMMON PRESSURE VESSELS
- 12 PRESSURE VESSELS ARE USED; TOTAL 24 CELLS
- CAPACITY IS 23 AMP-HOURS
- CYCLE LIFE ~30000 CYCLES (5700 CYCLES/YEAR X 5 YEARS)
- BATTERY OCCUPIES 6 OF 7 BAYS IN THE BATTERY/PROPULSION MODULE, 2 PRESSURE VESSELS PER BAY
- HEAT PIPE IS USED TO SPREAD HEAT EVENLY BETWEEN ALL 7 BPM BAYS
- DUAL-SLEEVE CELL MOUNTING USED TO EQUALIZE CELL TEMPERATURES WITHIN A PRESSURE VESSEL
 - LIFETIME BATTERY AVERAGE TEMPERATURE ~10°C
 - CELL-TO-CELL GRADIENTS <3°C



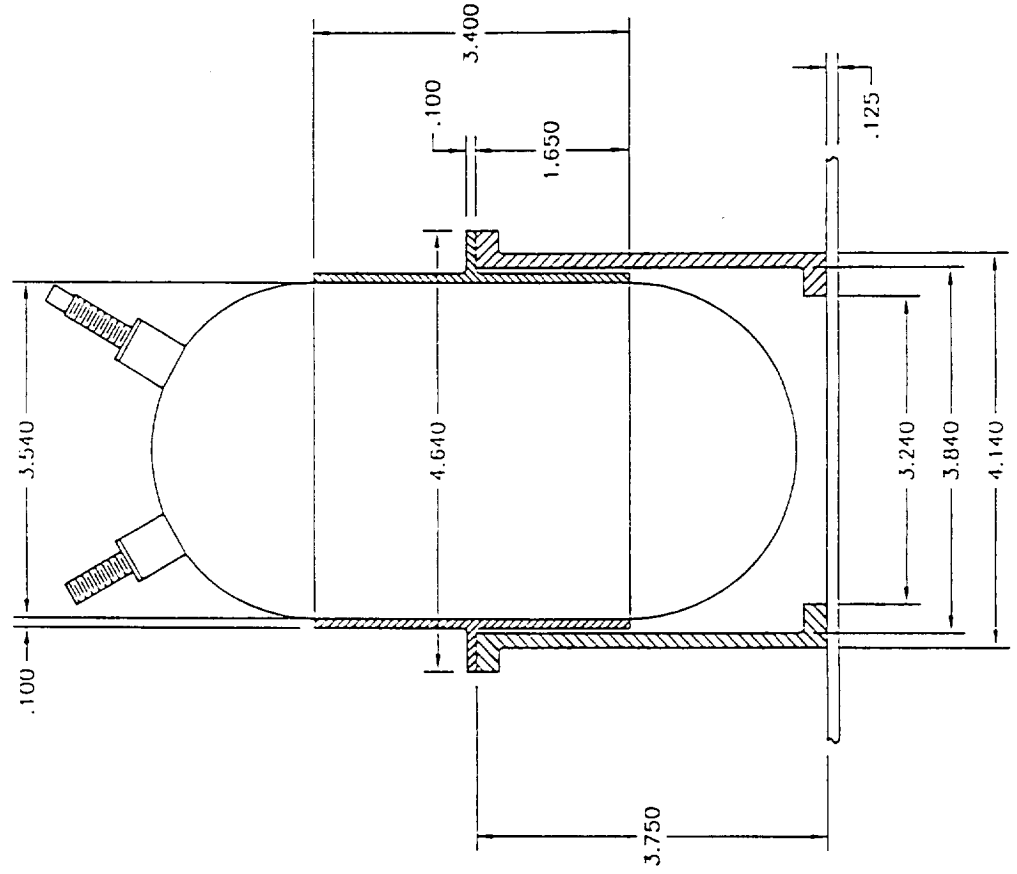
BATTERY LAYOUT

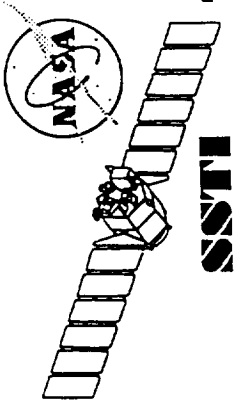
TRW





BATTERY CELL MOUNTING



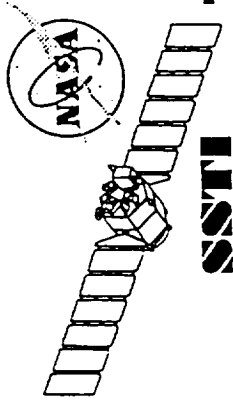


BATTERY UNIT SPEC'S



PERFORMANCE REQUIREMENTS

- LEO ORBIT - 95 MINUTE ORBIT (35.3 MINUTE ECLIPSE)
- FIVE YEAR GOAL - 30,000 CYCLES
- ECLIPSE DISCHARGES AT APPROXIMATELY 0.5 C
- MAXIMUM DEPTH OF DISCHARGE IS 30%
- NORMAL OPERATING VOLTAGE RANGE 24.0 TO 38.4 VOLTS
- BATTERY CLAMP TO THE BUS

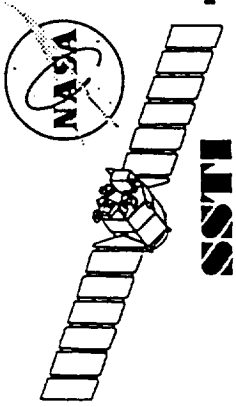


BATTERY UNIT SPEC'S



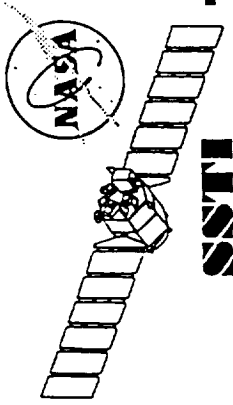
DESIGN AND CONFIGURATION

- TWELVE 23 Ah NICKEL-HYDROGEN CPV'S IN SERIES
- BATTERY CONFIGURATION CONSISTS OF SIX (6) MODULES OF TWO CPV'S DISTRIBUTED AROUND INBOARD SIDE OF AFT FACING BATTERY RADIATOR
- EACH VESSEL IS CONTAINED WITHIN A THERMAL SLEEVE AND MOUNTING FLANGE WHICH IN TURN ARE MOUNTED TO ALUMINUM SLEEVES PERPENDICULAR TO THE BASEPLATE
- CELL HEAT IS PASSIVELY CONDUCTED FROM THE CELL TO THE BASEPLATE WHICH RADIATES DIRECTLY TO SPACE
- BATTERY WEIGHT: 55.5 LBS



FUNCTIONAL DESCRIPTION **7R11**

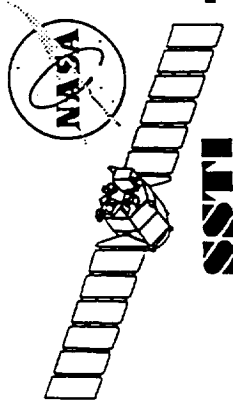
- CHARGE
 - PRIMARY CHARGE CONTROL IS PROVIDED BY Ah INTEGRATION PERFORMED BY THE OBC
 - CHARGE RATE IS THREE STEP PROCESS WITH RECHARGE RATIOS NOT EXCEEDING 1.10
 1. INITIAL CURRENT OF 0.4 C
 2. TAPER CURRENT
 3. FINISH CHARGE AND OVERCHARGE AT 0.2 C
 - BACKUP CHARGE CONTROL IS PROVIDED BY SENSING BATTERY TEMPERATURE TURNAROUND AT THE ONSET OF OVERVOLTAGE
 - CHARGE VOLTAGE SHALL NOT EXCEED 38.4 VOLTS



FUNCTIONAL DESCRIPTION **7R11**

(CONT'D)

- DISCHARGE
 - BATTERY IS CAPABLE OF PROVIDING AT LEAST 325 WATTS DURING A 35.3 MINUTE ECLIPSE AT A DEPTH OF DISCHARGE NOT EXCEEDING 30%
- RECONDITIONING
 - BASELINE DESIGN DOES NOT INCLUDE RECONDITIONING
- THERMAL CONTROL FEATURES PERMIT OPERATION WITHIN FOLLOWING CONSTRAINTS
 - BATTERY ORBITAL AVERAGE TEMPERATURE SHALL BE NO GREATER THAN 10°C
 - TEMPERATURE GRADIENT BETWEEN HOTTEST AND COLDEST VESSELS IN BATTERY SHALL NOT EXCEED 3°C



23 Ah - CPV DESIGN



- EAGLE-PICHER RNHC-23-1

- DUAL-STACK DESIGN

- POSITIVE ELECTRODE:

THIRTY SIX 0.030 INCH PLATES
80% SINTER POROSITY
1.65 GM/CC ACTIVE MATERIAL LOADING

- SEPARATOR:

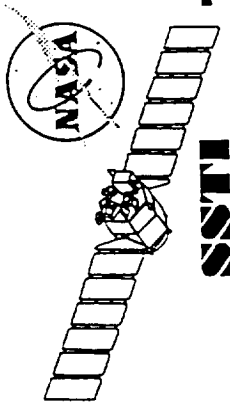
DOUBLE LAYER ZIRCAR

- ELECTROLYTE:

31% FINAL KOH CONCENTRATION

- PRECHARGE:

NICKEL



23 Ah - CPV DESIGN (CONT'D)



- **PRESSURE VESSEL:**

INCONEL 718

MAXIMUM DESIGN PRESSURE - 800 PSI

- **DIMENSIONS:**

3.506 INCH (8.905 cm) DIAMETER

7.60 INCH (19.304 cm) OVERALL LENGTH

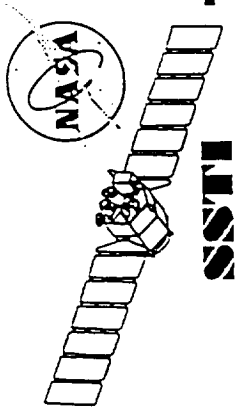
- **WEIGHT:**

MAXIMUM VESSEL CELL WEIGHT

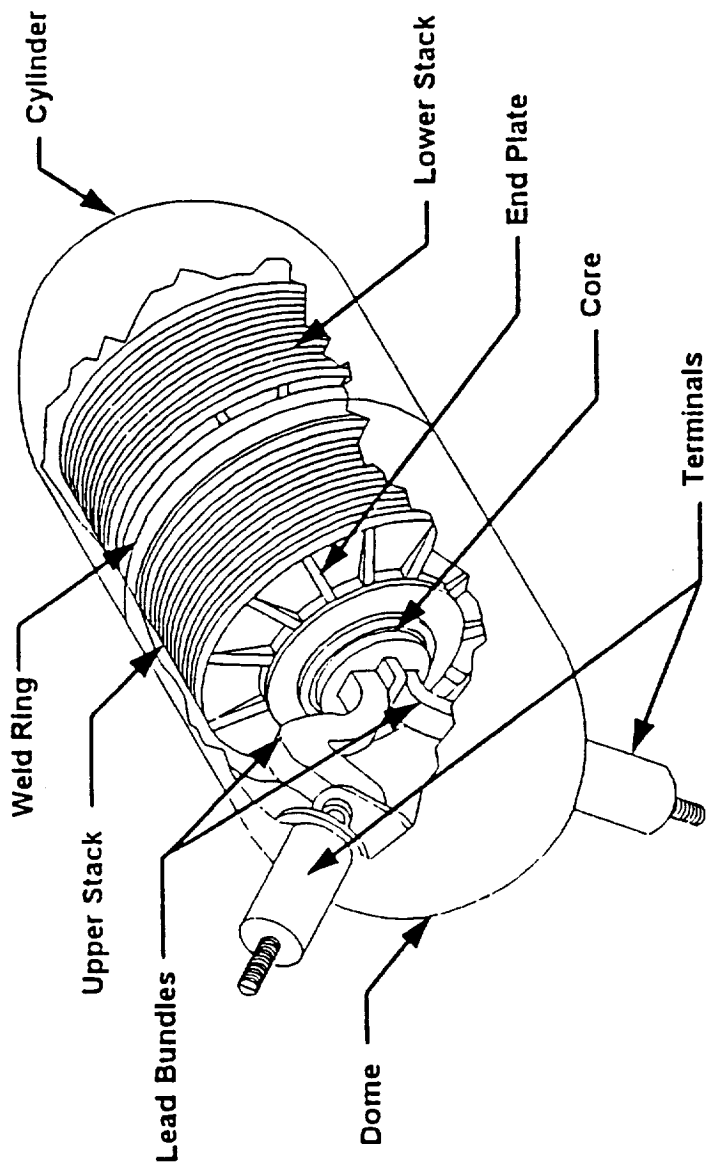
3.08 LBS (1400 GMS)

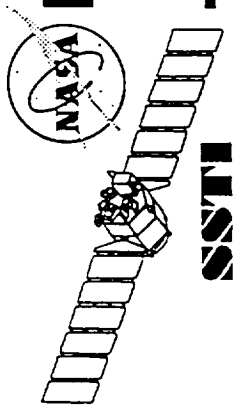
CELL LOT - AVERAGE VESSEL WEIGHT

3.04 LBS (1380 GMS)

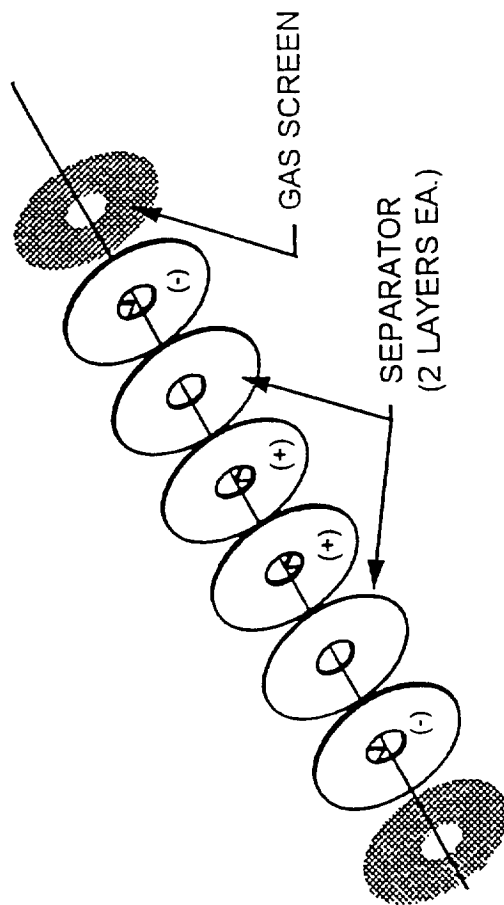


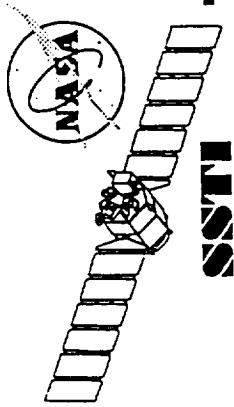
CPV RABBIT EAR "DUAL STACK"





ELECTRODE STACK ASSEMBLY





ACCEPTANCE TEST DATA

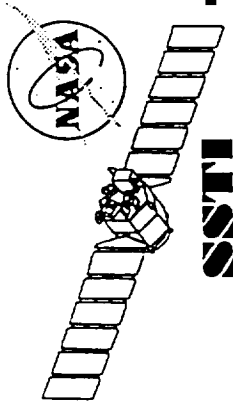


CELL ATP DATA (19 VESSELS)

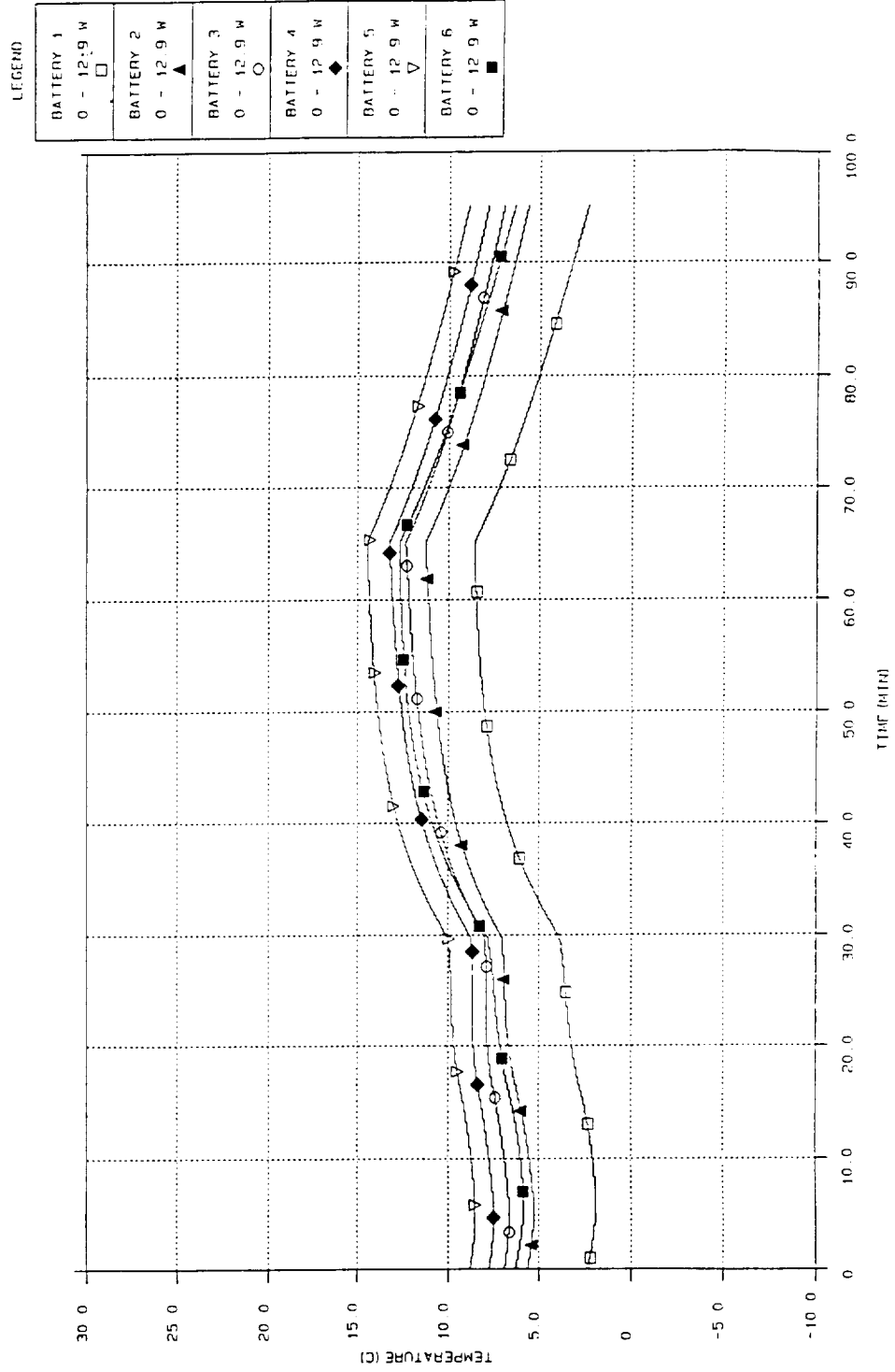
TEST	<u>0°C CAPACITY</u>	<u>10°C CAPACITY</u>	<u>20°C CAPACITY</u>
CAPACITY (A-Hr)	30.8	28.5	24.2
EOC (VOLTS)	3.154	3.077	2.996

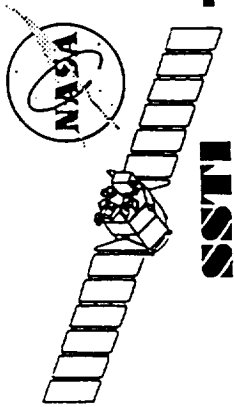
BATTERY ATP DATA (12 VESSELS)

TEST	<u>CHARGE RETENTION AT 10 C</u>		
	INITIAL	AFTER 72 HOURS	% RETENTION
CAPACITY (A-Hr)	28.5	25.8	90.3

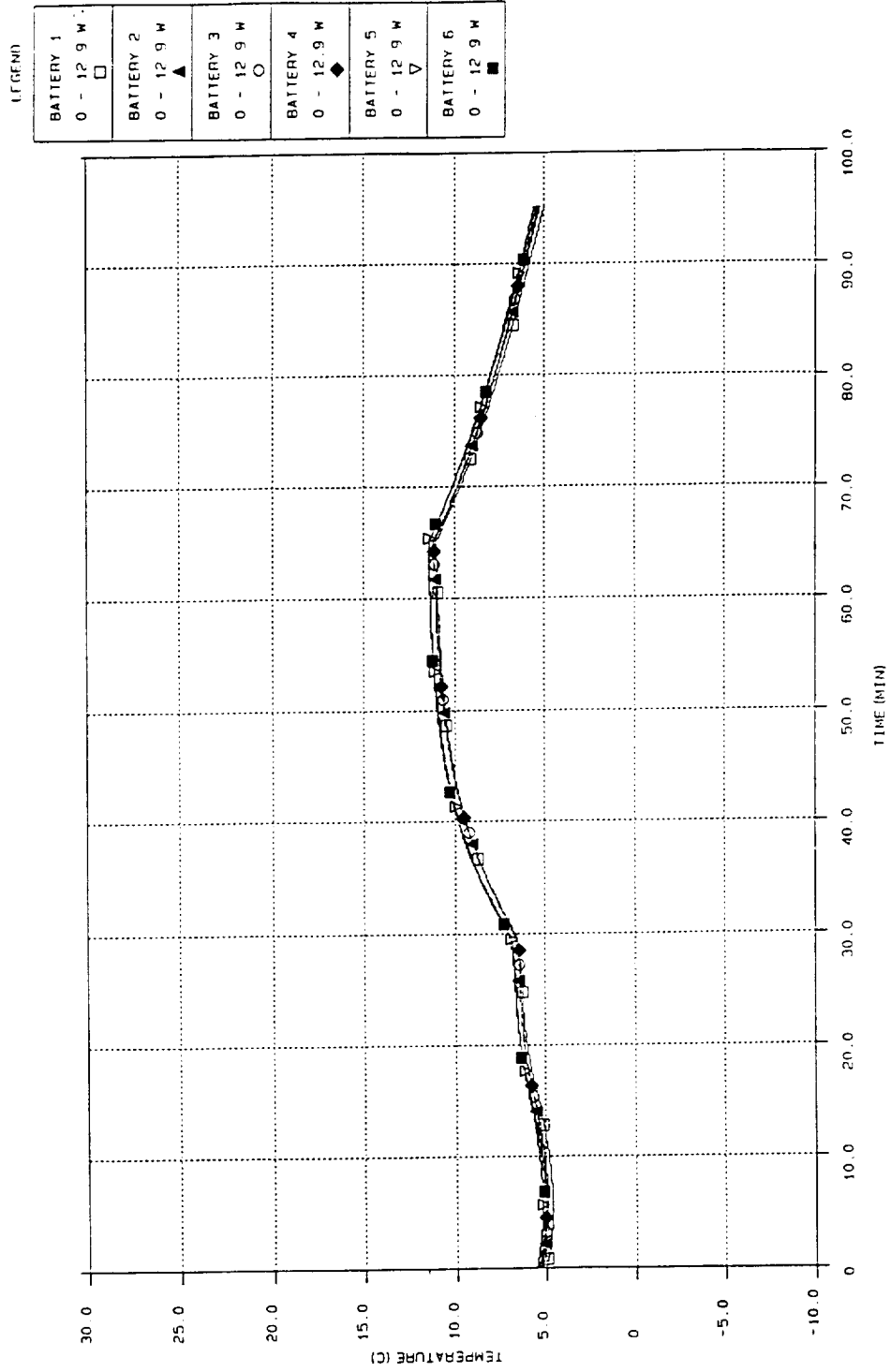


BATTERY TEMPERATURES WITHOUT HEATPIPE





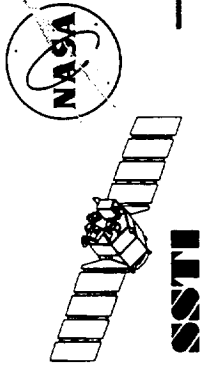
BATTERY TEMPERATURES WITH HEATPIPE





LIGHTWEIGHT GFRP STRUCTURES

Al Barrett
August 8, 1996



INTRODUCTION



- GFRP composite structure: an enabling technology for the SSTI mission
- Attributes of GFRP composite structure useful to SSTI mission
 - Lighter than equivalent aluminum structure
 - High modulus/density ratio
 - High thermal conductivity/density ratio in fiber direction (for high modulus pitch fibers)
 - High strength/density ratio (for strength - selected fibers)
 - Low CTE
 - Tailorable properties
 - Self-fixturing of bonded structural assemblies
- Composites used for all major SSTI structural components
- Metallic fittings used in selected joint locations



Design/Implementation Issues In Using GFRP Composite Structure



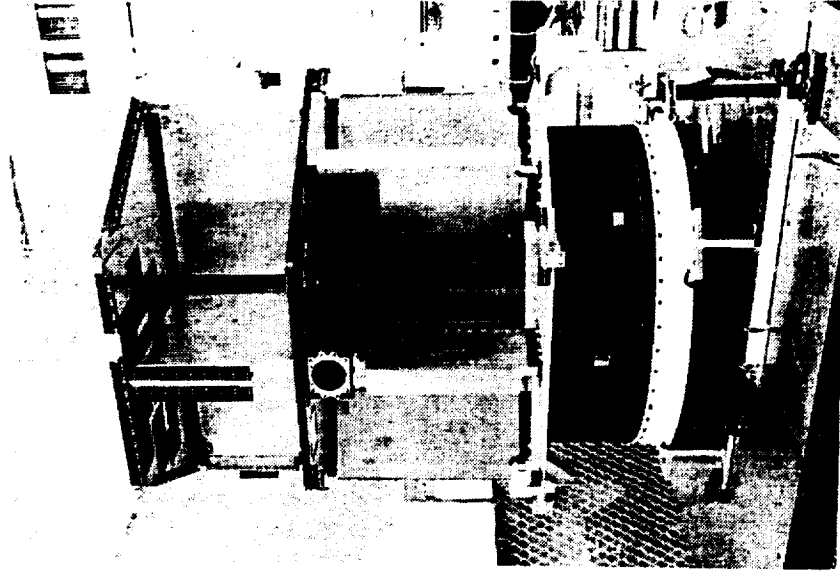
- Higher cost than equivalent aluminum structure
- Zero ductility: sensitive to peak strains
- Low compressive strength of thermally conductive pitch fibers
- Low thermal conductivity perpendicular to fiber direction (resin dominated)
- Mix of fibers required to obtain optimum combinations of strength, stiffness, thermal conductivity
- Properties workmanship dependent
- Low strength perpendicular to fiber direction
 - Susceptible to delamination failure mode
 - Load-spreading features required for concentrated loads, e.g., bolts under high pre-load
- Low electrical conductivity
- CTE mismatch with bonded metallic fittings



STRUCTURE ASSEMBLY

TRW

- Modular configuration to facilitate parallel integration
 - Battery/propulsion module (BPM)
 - Avionics module (AM)
 - Payload module (PM)
- Each module designed to use space efficiently
 - Propellant tank inside central cylinders of AM & PM
 - Equipment mounted on radial panels of AM & PM
- Structural load paths adapted to different module configurations
 - Four point AM/PM axial load path
 - Central cylinder AM primary structure
 - Internal shear webs in BPM transfer load from inner to outer cylinder
- Panels and cylinders: honeycomb sandwich with GFRP face sheets
 - Cylinders M60J
 - Panels M60J, P100, K1100X
 - SADA torque box T300, M60J
 - Laminates tailored to match strength, stiffness, conductivity requirements
- Aluminum foil ground plane



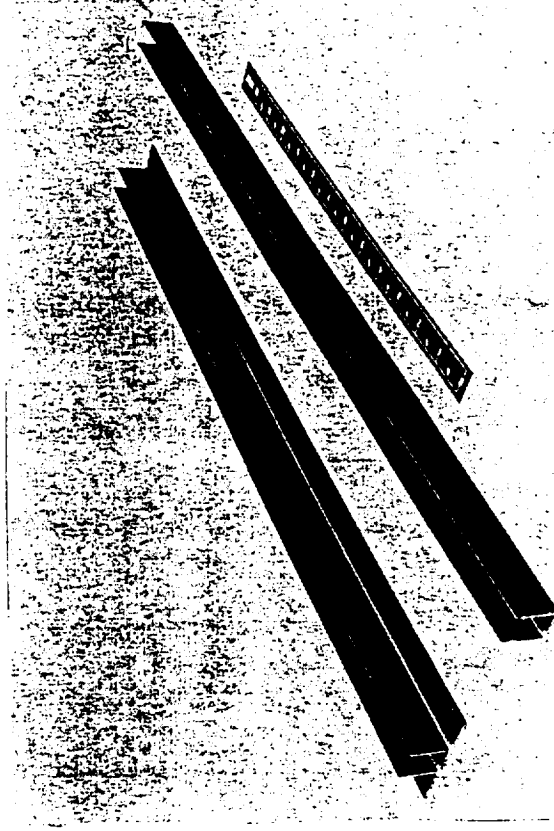
Structure assembly without AM and PM radiator panels



RESIN TRANSFER MOLDED (RTM) STANDARDIZED JOINT SECTIONS



- Standardized shapes used for panel - panel joints
 - Primary structure
 - Secondary brackets & housings
 - Used for both bonded joints and bolted joints
- Resin transfer molding process (RTM) used to form joint sections
 - Excellent dimensional accuracy
 - High strength

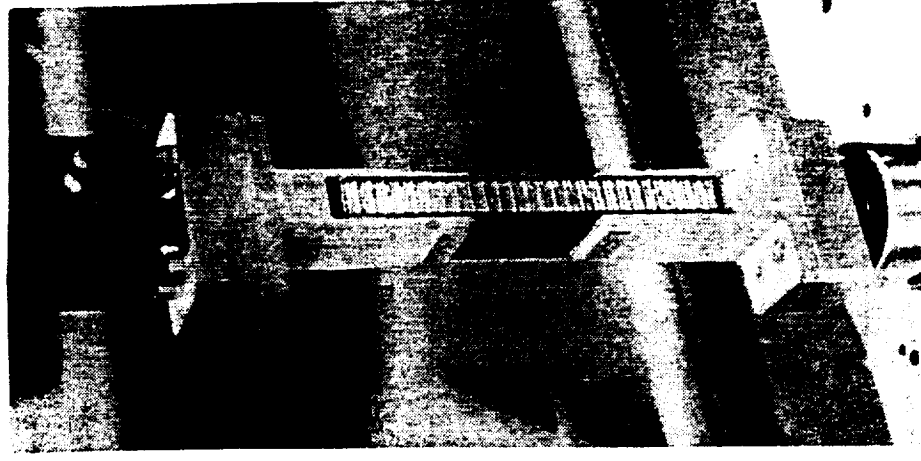




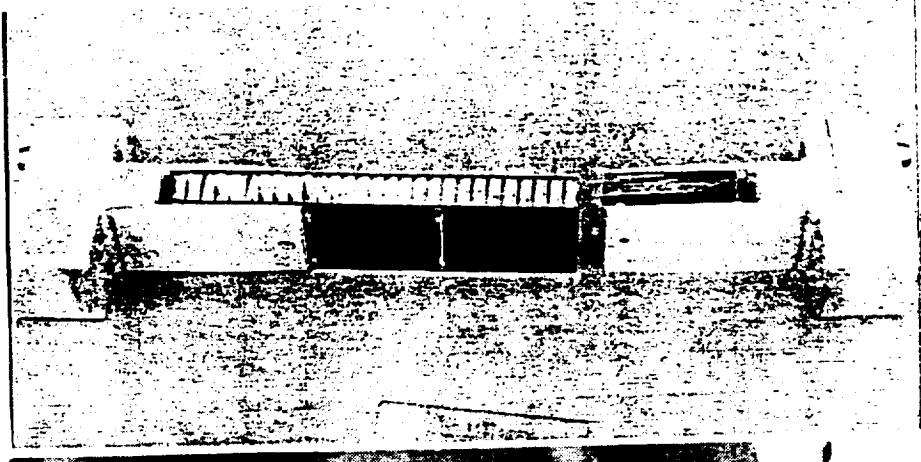
TYPICAL JOINT DEVELOPMENT TEST



- Test objectives:
 - Verify analytical strength predictions
 - Determine critical failure modes
 - Validate design prior to starting fabrication of flight hardware
- Test article
 - Critical joint sample
 - Flight-like materials and processes
- Test loading - tension test to failure



Test setup



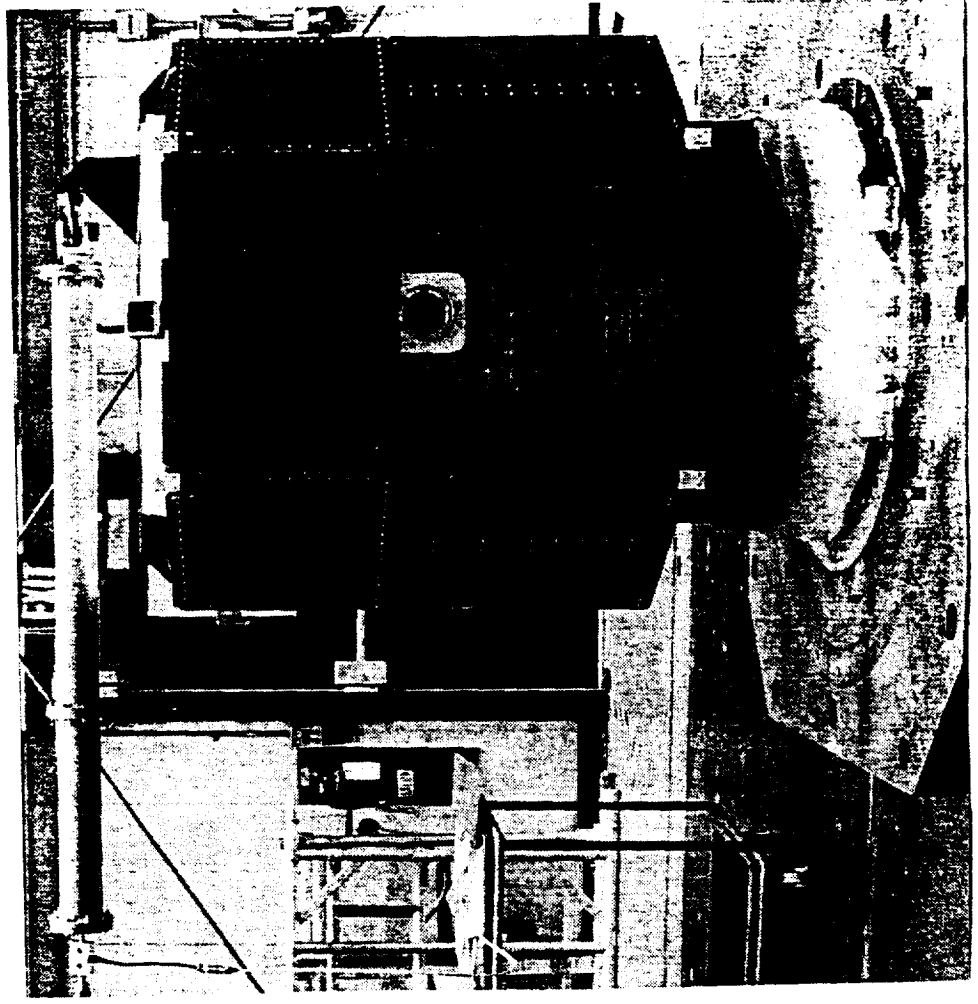
After loading to failure
(First-ply failure mode)

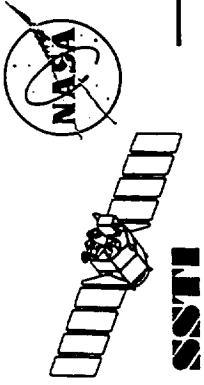


TRW

STATIC PROOF TEST

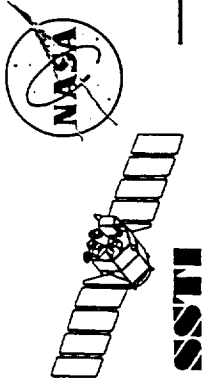
- Test article: Structure assembly
- Test objective: Verify strength adequacy of primary structure
 - Design
 - Workmanship
- Induced load magnitudes
 - 120% limit line load at LV I/F, BPM/AM joint, AM/PM joint
- Applied load parameters
 - Magnitude
 - Direction
 - Distance from LV I/F
- Test load reaction capability designed into lift points
- Test results: Reacted loads without damage





Star Tracker and Earth Sensor Technologies

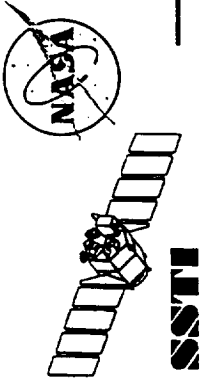
Paul Parry
TRW GN&C Subsystem Manager



Introduction



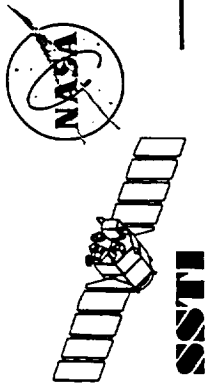
- Earth Sensors and Star Trackers are Typically Expensive, Heavy, and Consume Substantial Power
- Lewis Will Be First to Fly the Latest in Both Earth Sensor and Star Tracker Technologies
 - Both units are lower in cost, weight, and power than previous models



Lewis Earth Sensors



- EDO Barnes Model 13-477
 - Three single-axis sensors provide roll and pitch signals with redundancy/sun intrusions
 - Three thermopile detectors per sensor for background calibration and reduced earth radiance errors
- Lower Cost, Weight and Power is Obtained by Placing More Functions in Flight Software
 - Over 200 lines of code in data processing function
 - Over 130 database coefficients

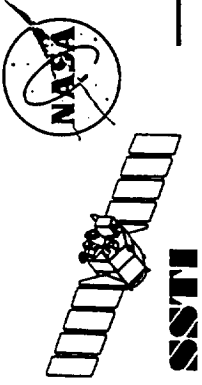


SSTI Lewis Miniature Earth Sensors



- Lewis Earth Sensors are the lightest, lowest power sensors available

Earth Sensor Model	No. of Boxes for Redundant System	Weight for Redundant Sys. (lbm)	Power (watts, ave)	Accuracy (deq. 3-sigma)
Barnes 13-477	1	2.0	0.3	0.8
ITHACO CES	3	11	8.0	0.1
ITHACO T-Scanwheel Optics	3	6.1	4.0	0.2
Space Sciences 1060 HSA	3	5.2	2.5	0.02



Lewis Star Trackers

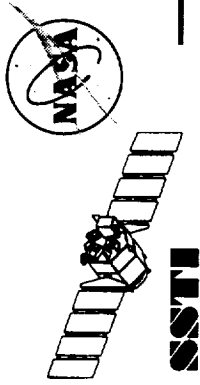


- Two Trackers on Lewis
 - HDOS HD-1003 Narrow Field of View (NSTA)
 - HDOS HD-1003 Wide Field of View (WSTA)
- Narrow FOV Tracker is Bus Instrument Required to Meet HSI Payload Pointing Knowledge Requirements
- Wide FOV Tracker is Technology Demonstration (Gyroless Attitude Determination)

SSTI Lewis HD-1003 Star Trackers

- Lewis Trackers are among the lightest, most capable ever produced

Tracker Model	Field of View (deg)	Weight with Shade (lbm)	Power (watts, ave)	No. of Stars Tracked	Accuracy (arcsec, RMS)
HDOS HD-1003 NFOV	8x8	7.5	7	6	6
HDOS ASTRA 1	7x9	18	20	1	10
Ball CT-601	8x8	22	12	5	6
HDOS HD-1003 WFOV	20x20	6.4	7	6	24
Ball CT-631	20x20	6.3	12	5	21



R3000 Based On Board Computer (OBC)

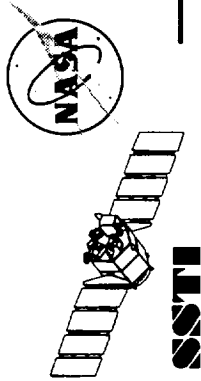
Peter McShane

TRW Space & Electronic Group

One Space Park

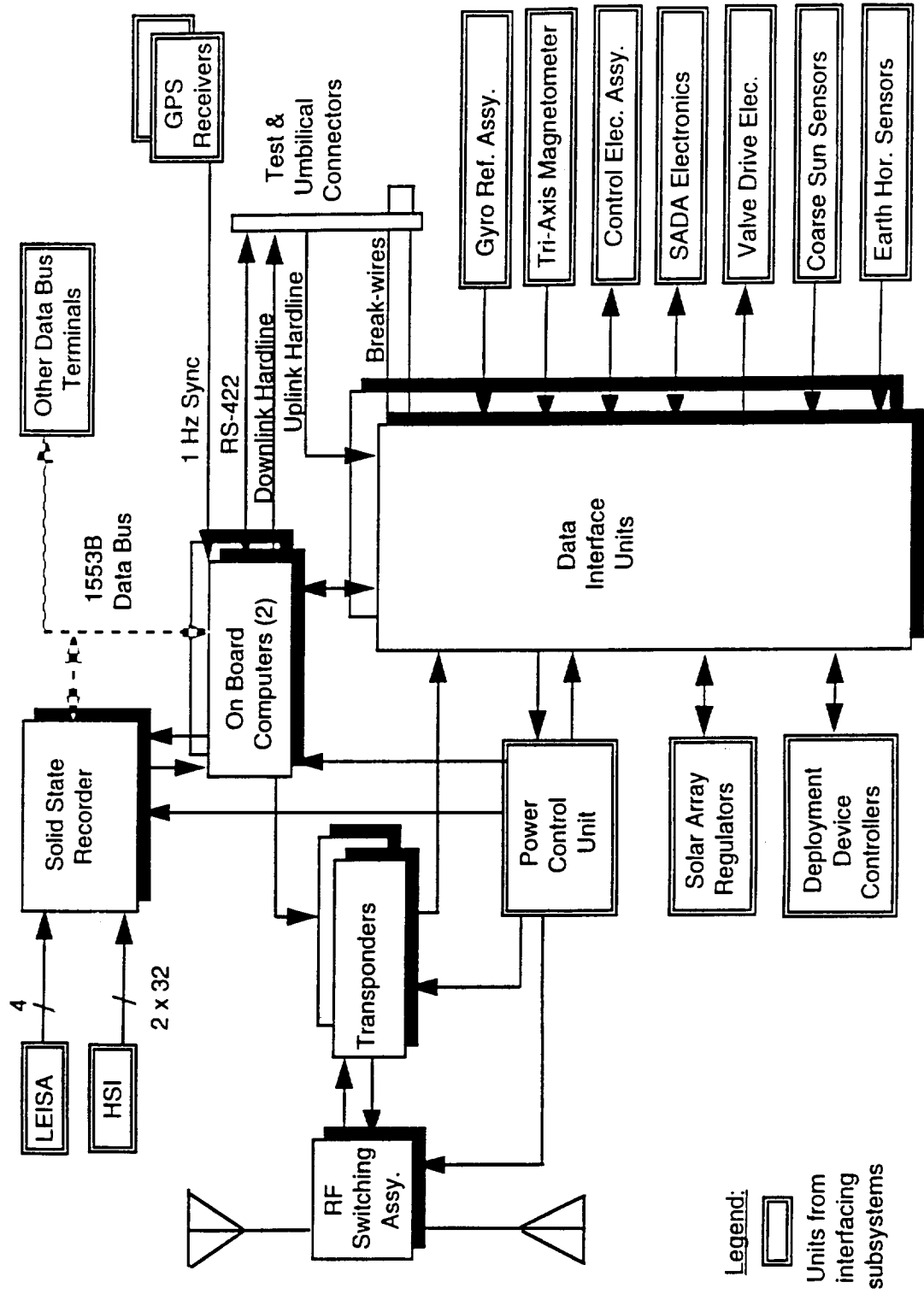
Redondo Beach, CA. 90278

August 8, 1996



OBC Core of DMS Subsystem

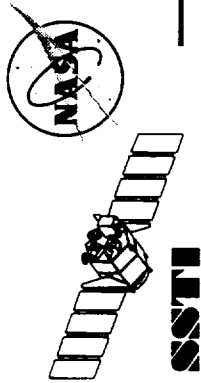
TRW



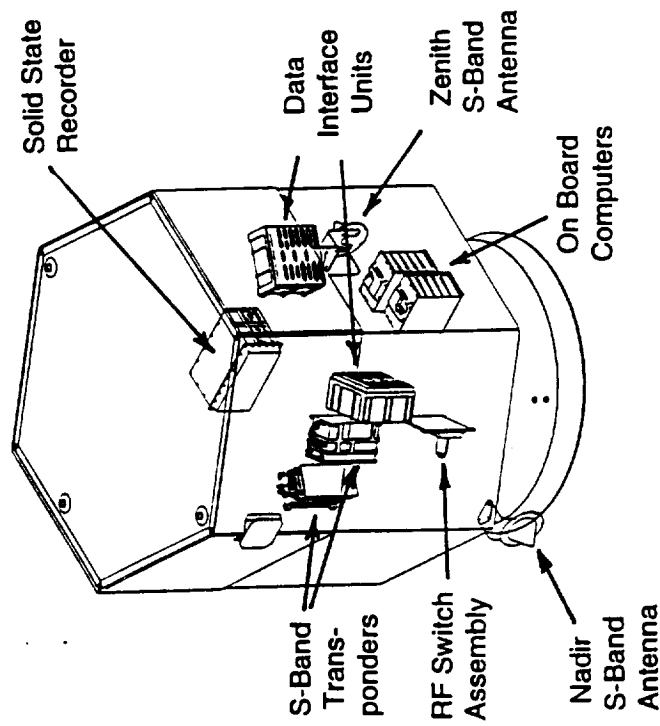
Legend:



Units from interfacing subsystems



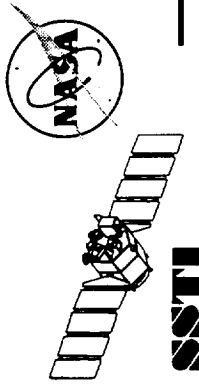
OBC Location on SSTI



Function:

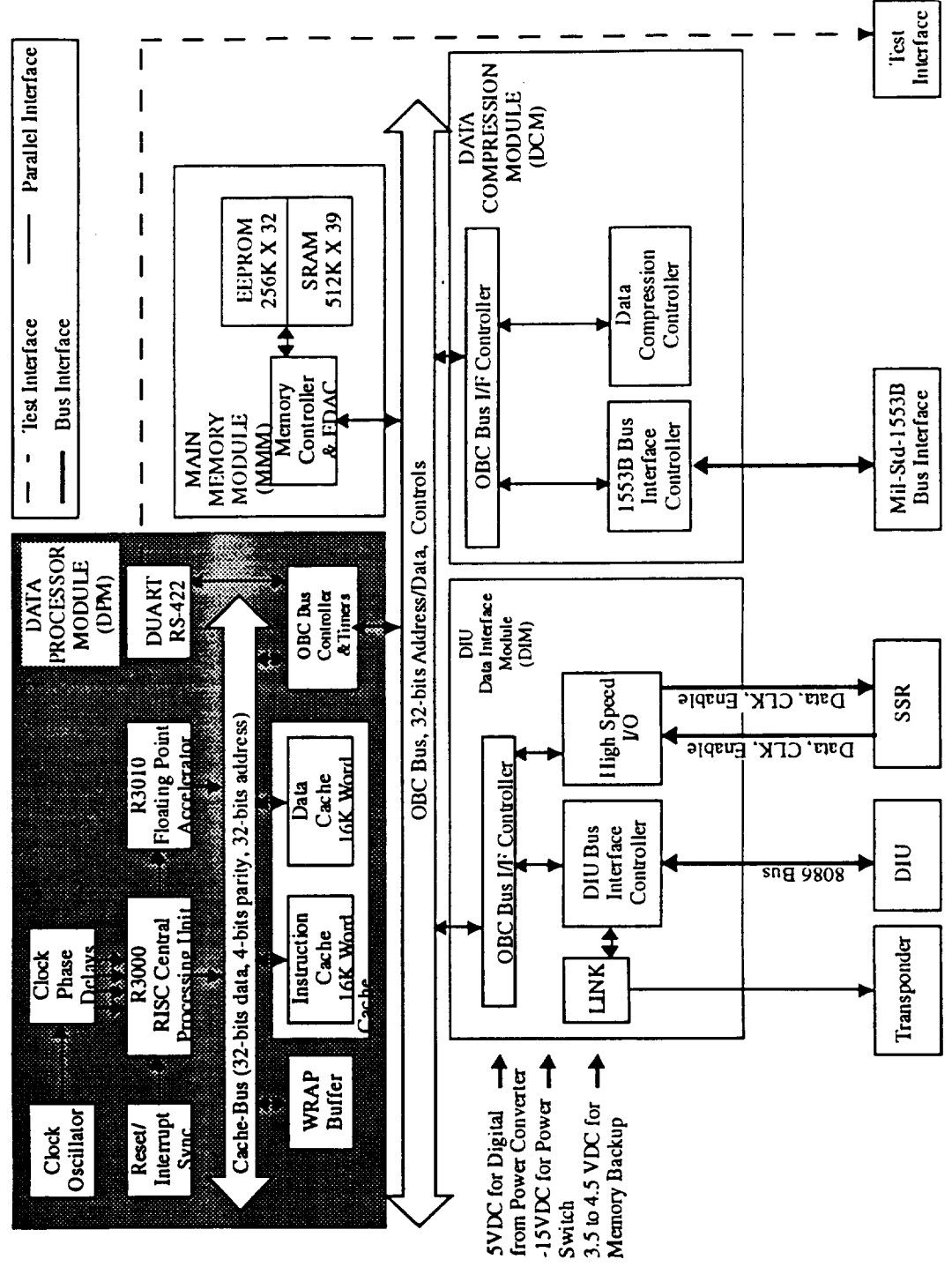
- Sensor Data Acquisition, Storage Compression and Formatting for Downlink
- Receive and decode serial commands
- Format and send serial telemetry to xponder

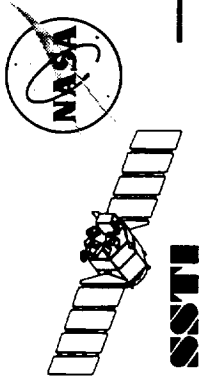
DMS Equipment Locations



SSTI/OBC Architecture

TRW





OBC Capabilities



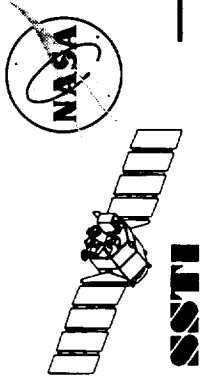
- Description

- CPU – R3000 with R3010 FPU, running at 32.786 MHz (capability 50 MHz)
- Cache – 16K x 60 words of I-Cache, 16K x 60 words of D-Cache
- RAM – 2M bytes of EDAC SRAM
- EEPROM – 1M byte of EEPROM
- I/O – Many I/O cards developed
 - – 1553*, STDN*, SGLS, 8086*, Loral HSS, SSR*, Laser xlink, TRW EPIC, Discrete I/O, Analogue I/O, Tape Deck, Data Compression*, RS422*

- Performance

- Throughput – 12.7 Mips (VAX mips) @ 16.387 MHz
 - 18.0 Mips (VAX mips) @ 25.000 MHz
- Weight – < 7 lbs/unit
- Size – 7.75" x 6.82" x 4"
- Power – 18W typical
- Radiation – Main Components (CPU, RAM, FPU) tested to 150K rad

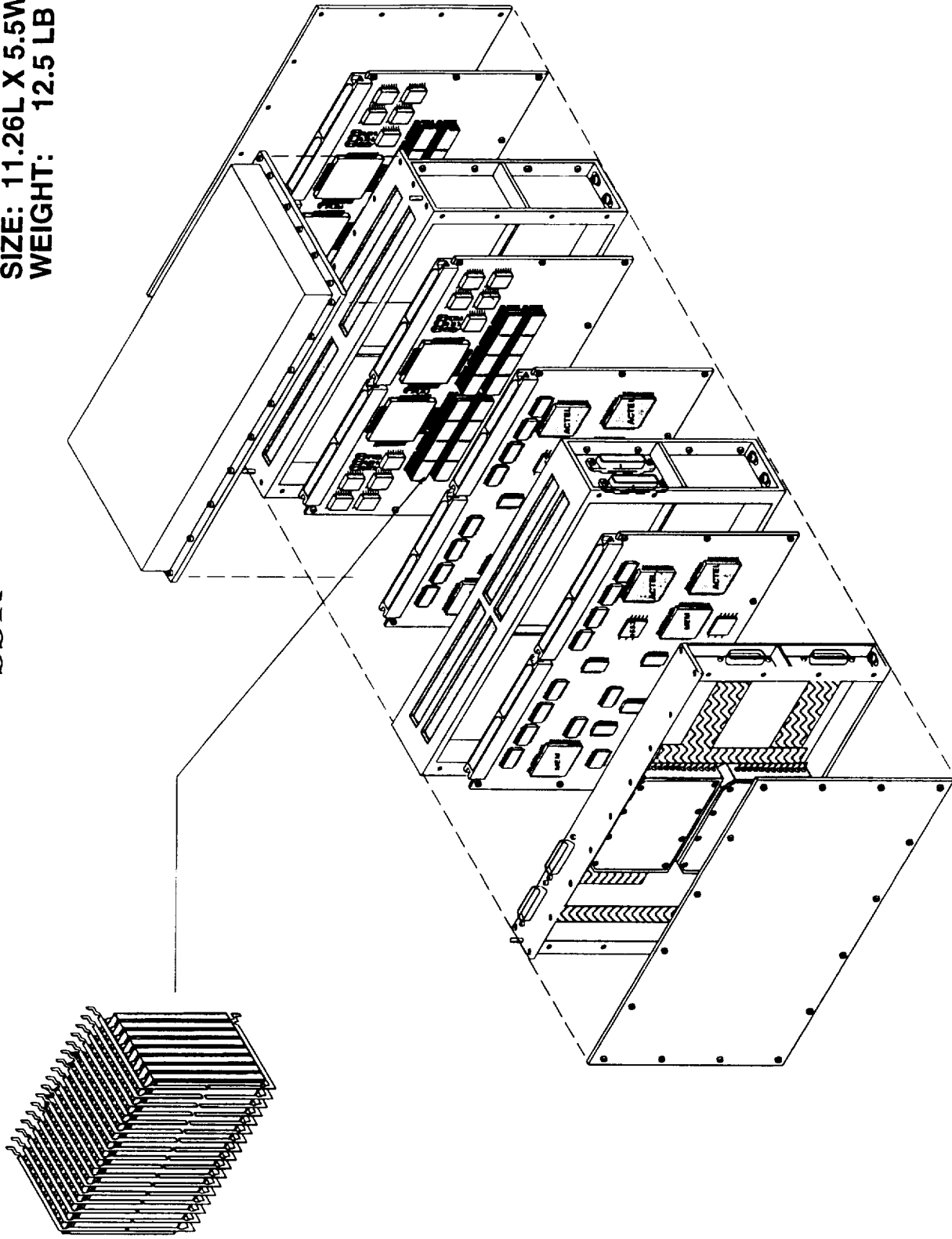
*Used on SSTI

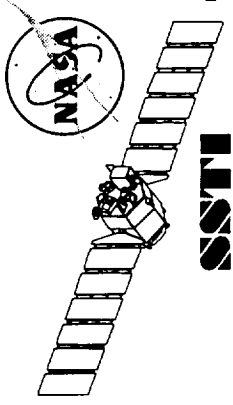


Solid State Recorder

Derek Au

SSR
SIZE: 11.26L X 5.5W X 7.5.0H
WEIGHT: 12.5 LB EST.

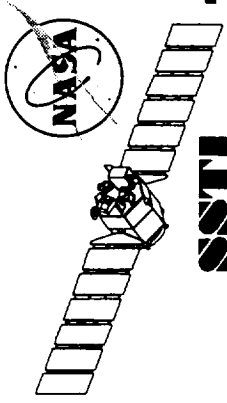




SSTI Solid State Recorder



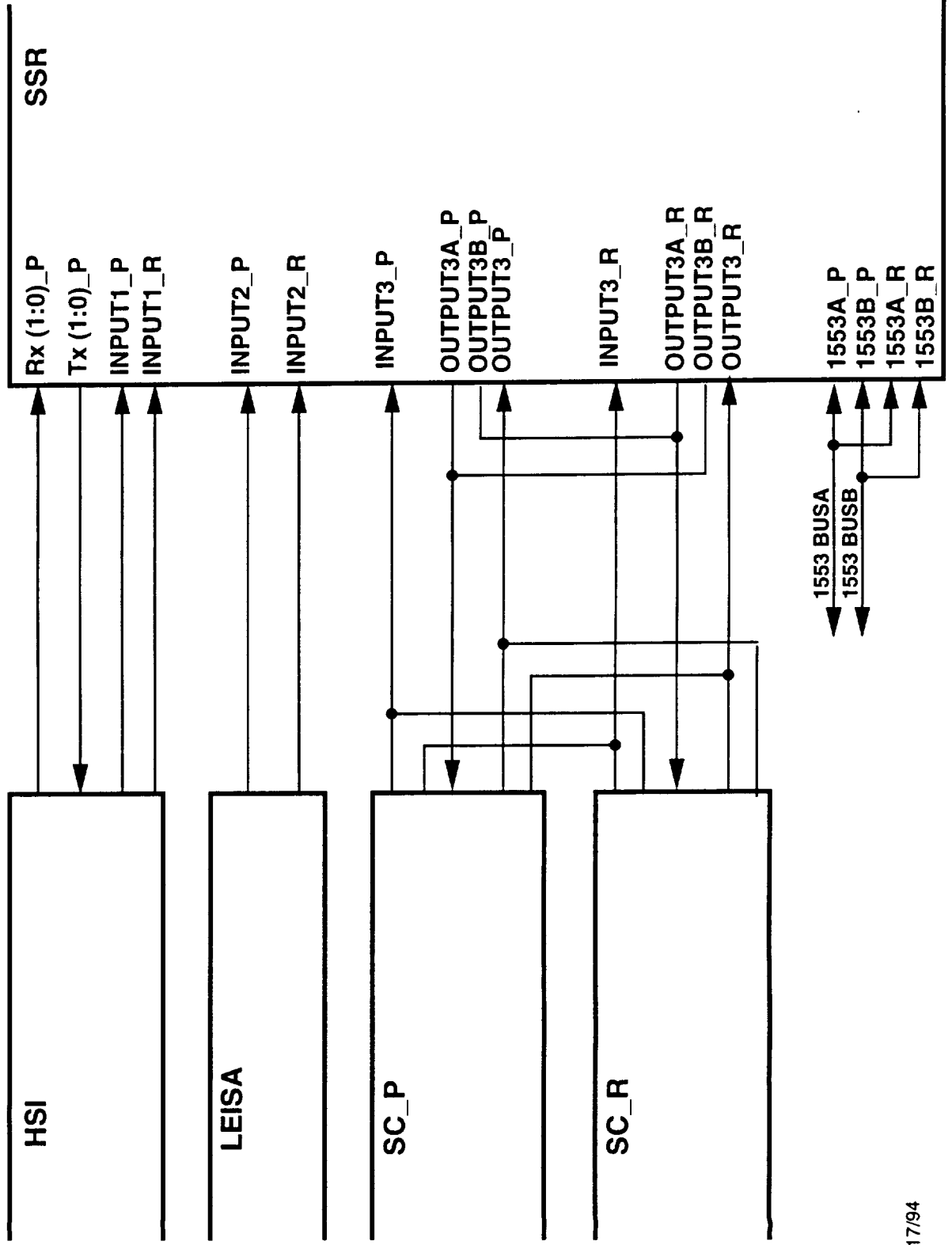
- 4 Giga-bits Beginning of Life Memory Capacity
- 800 Mbps Aggregate Read/Write Data Rate
- Fault Tolerant Design with internal Redundancy
 - Built in interface and Memory Tests
 - Chain Architecture allows for Graceful degradation
- Modularly Designed and Architected
 - Expandable Memory Capacity
 - Expandable Data Rate
- Simultaneous Asynchronous Read/Write Capability
- 1553 Command and Telemetry Interface
- Selectable Data Interfaces
 - 32 bit, 4 bit and serial interfaces
 - 1553 Data interface
- Advanced packaging and Design to Optimize Size, Weight and Power.

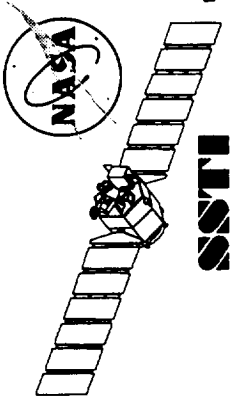


SSTI SSR Detailed Description



- Unit is comprised of Two CORE boards which are arranged into Two Chains.
 - Chains run in parallel to support Data Rates
- All memory is contained in Stacked memory modules on the CORE boards
- Interfacing is performed on the RIM Board
 - Developed by NASA Langley
 - Uses ACTEL FPGA's for circuit implementation
- Slices (CORE, RIM and Power Converter) are connected together via a Backplane Board
 - Clock and Power distribution are performed on the Backplane as well
- Power Converter slice is made up of Off-The-Shelf qualified Power Converters from Babcock.

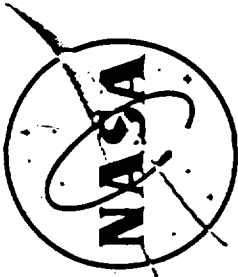




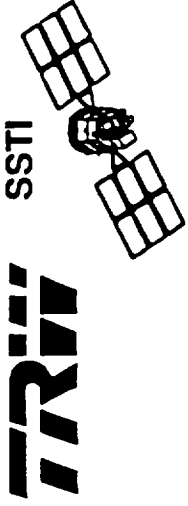
Advanced Packaging



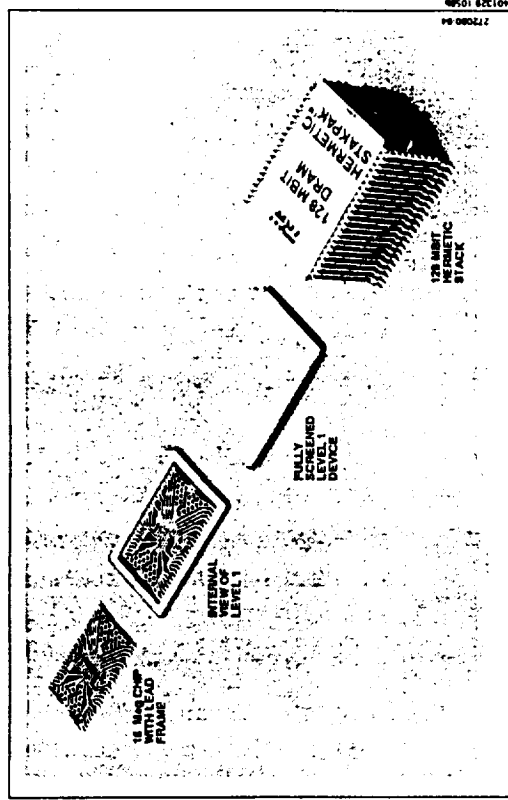
- Utilizes Stacked Memory modules for optimal RAM Density
- High Density ASIC packaging using Honeywell RICMOS IV Gate Array process.
- AIT Microwire board Technology used for higher density layout at Board level.
 - Very good Electrical performance and Thermal properties
 - Ease of routing allows for much shorter signal trace lengths
- Advanced Product Design Techniques to optimize Unit level packaging and expandability
 - Use of Backplane rather than Harness for Slice level interconnect
 - Chassis design is common for all slices
 - High Density connectors used to minimize Chassis size



Staktek Packaging

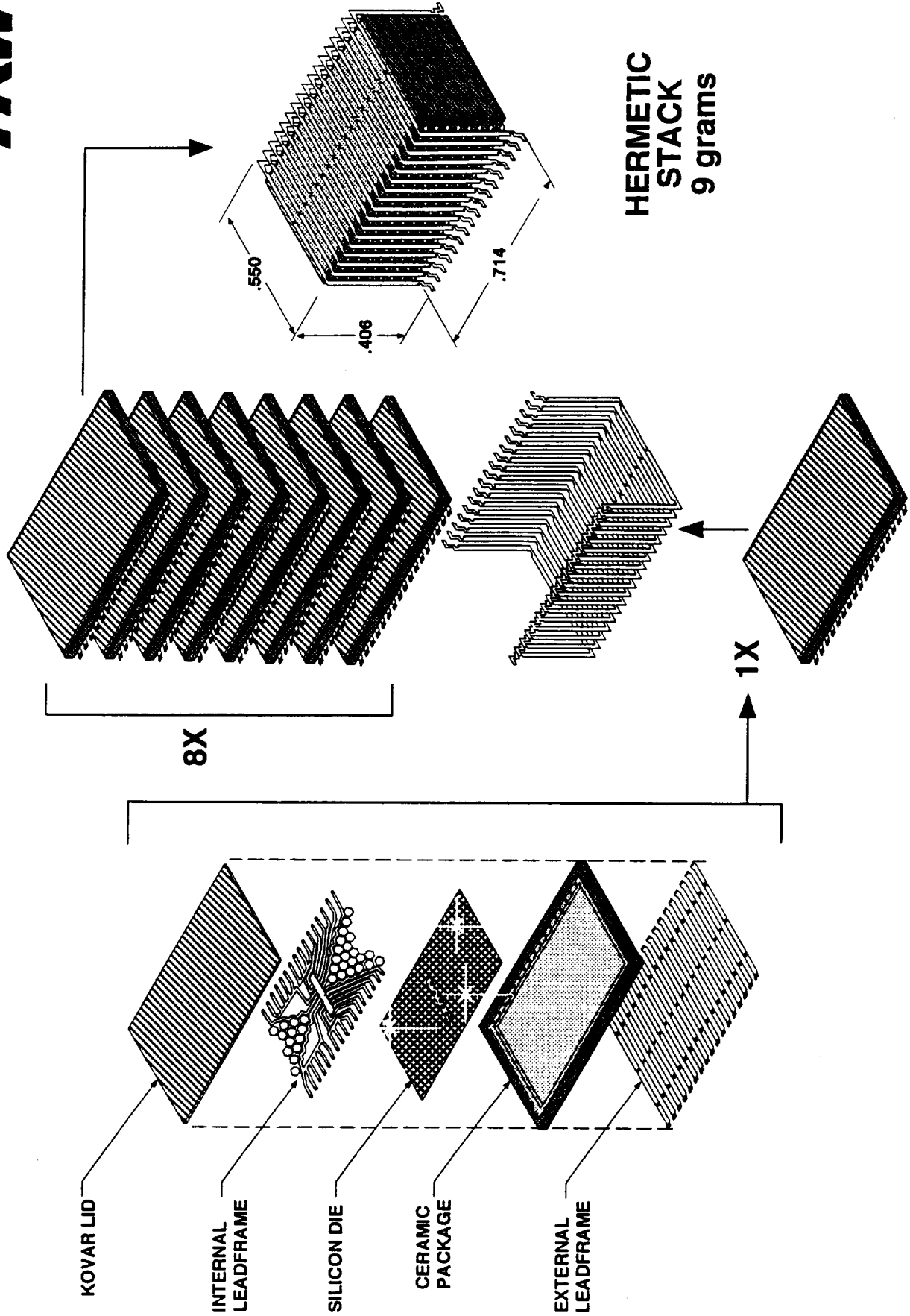


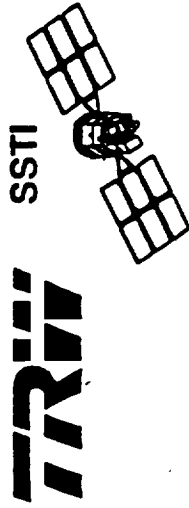
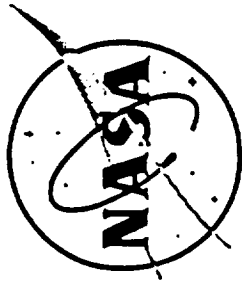
- 128 Mbit ceramic DRAM stack
- Qualified on IRAD
- 4 x size and weight reduction over standard packaging
- Excellent thermal properties
- Each of 8 layers fully tested prior to stack build-up





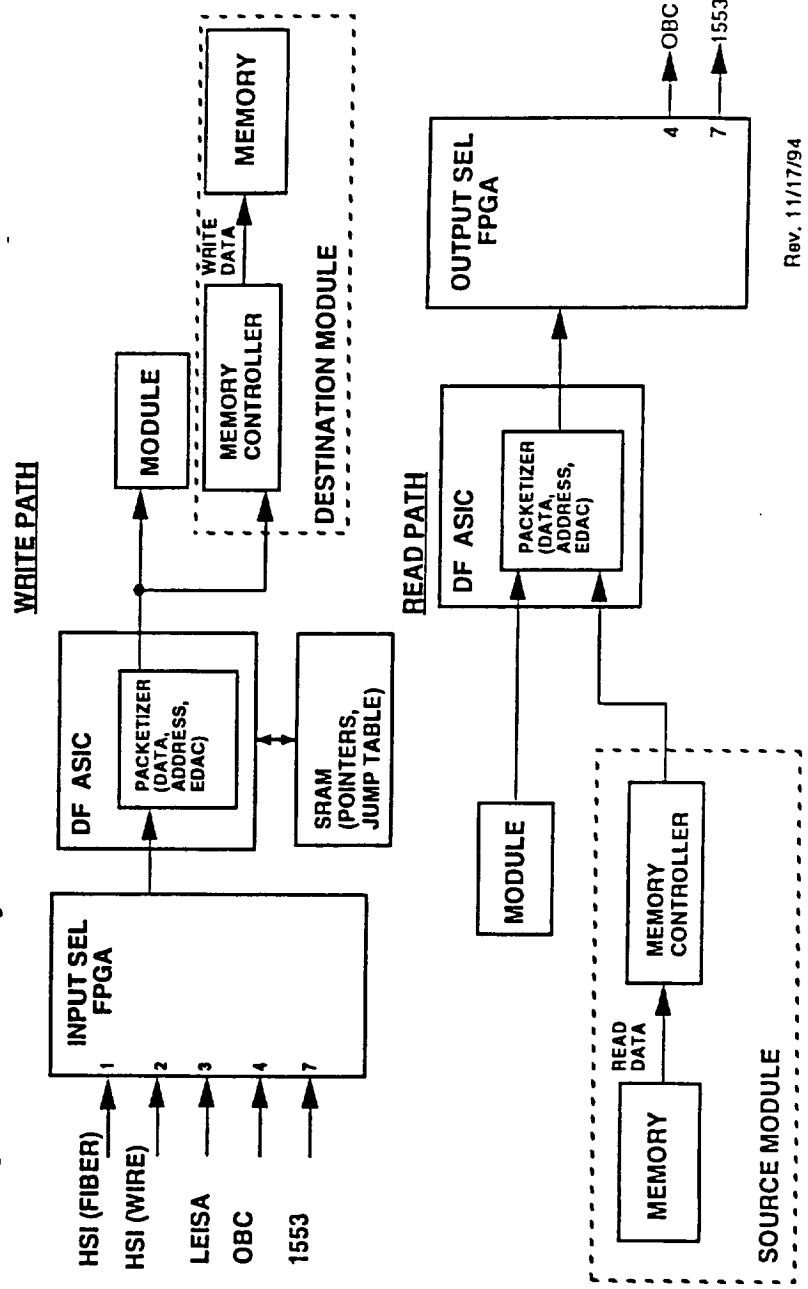
128 Mbit 8X HERMETIC STACK

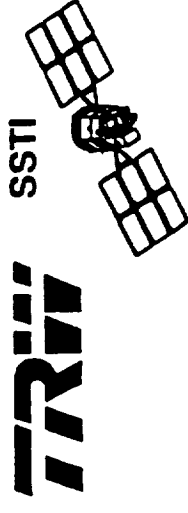
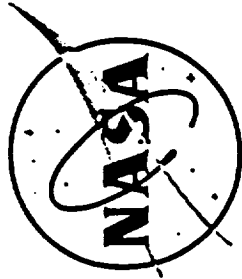




Memory Access

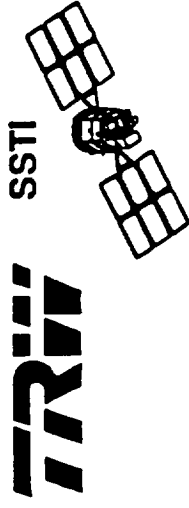
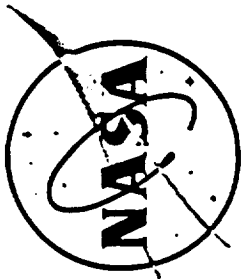
- Upon a write, data is packetized by the data formatter and sent to the appropriate module for storage
- Upon a read, a data packet is retrieved from the appropriate module and then depacketized by the data formatter





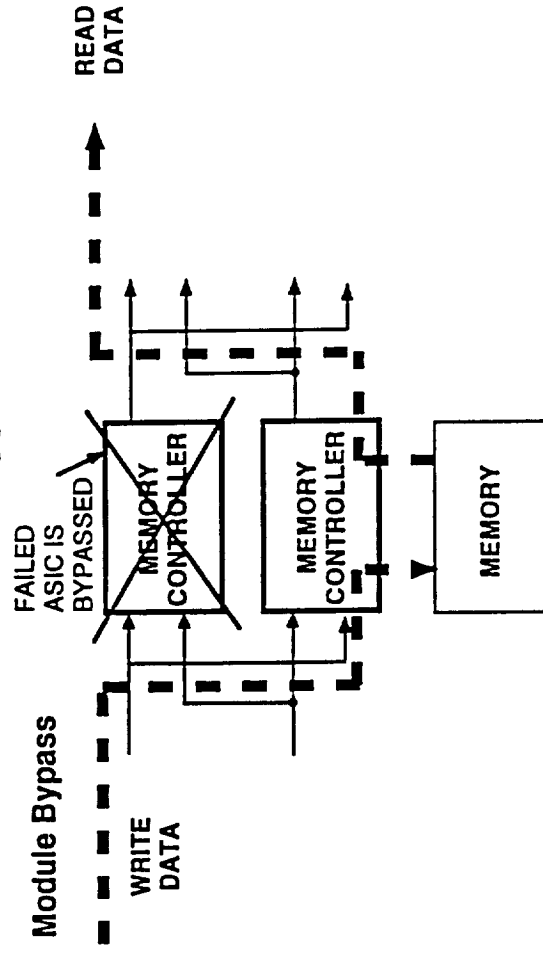
Fault Tolerance

- Multiple levels of fault tolerance provide excellent unit reliability
 - Redundant host interface and power converter
 - Memory controller bypass
 - Submodule bypass
 - Error detection, correction, and data scrub
- Hard errors detected via memory test and controller test
- Hard memory errors bypassed upon command
- Soft memory errors corrected through error-detection-and-correction-upon-read algorithm and periodic data-scrub algorithm utilizing 120/8 modified hamming code

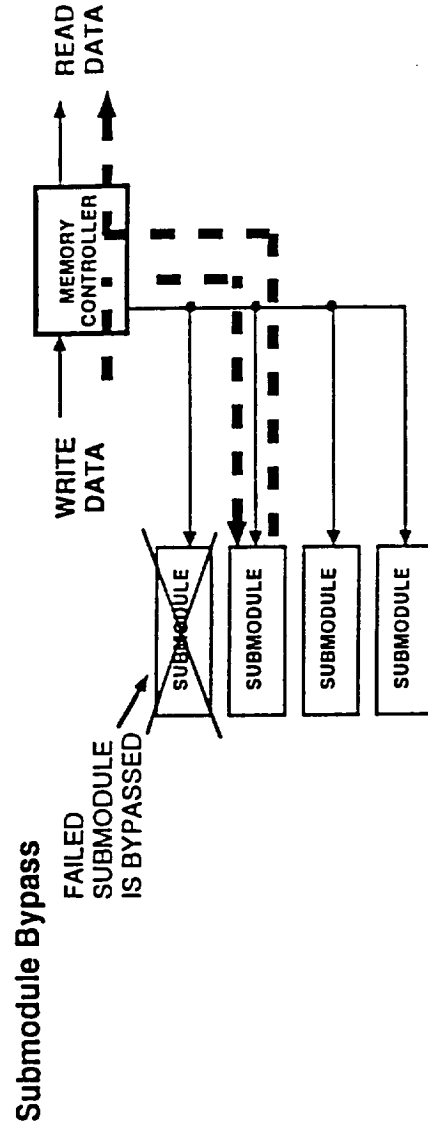


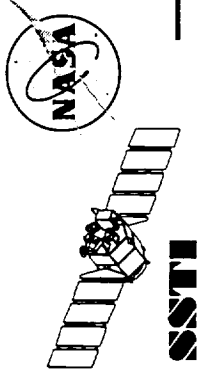
Fault Tolerance (Continued)

- Failed modules and bypassed via controller test



- Failed submodule detected and bypassed via memory test





August 8 – Day 1 Session 4

Independent Technology Demonstrations



1:00-5:00 – E2 Auditorium – Chair: Roger Avant

	<u>Speaker</u>	<u>Time</u>
• Miniaturized WFOV Star Tracker	Paul Parry/ Al Gauthier	1:00-1:30
• High efficiency Solar Cells	George Vendura/ Ed Gaddy	1:30-2:30
• GPS Attitude Determination	Frank Bauer	2:30-3:00
• Launch Loads Measurement System	Kirsten Kirkman	3:00-3:30
• Magnetically Suspended Reaction Wheel	Marty Beck	3:30-4:00
• Autonomous Orbit Control	Jim Wertz	4:00-4:30
• High Ratio Data Compression	Warner Miller	4:30-5:00

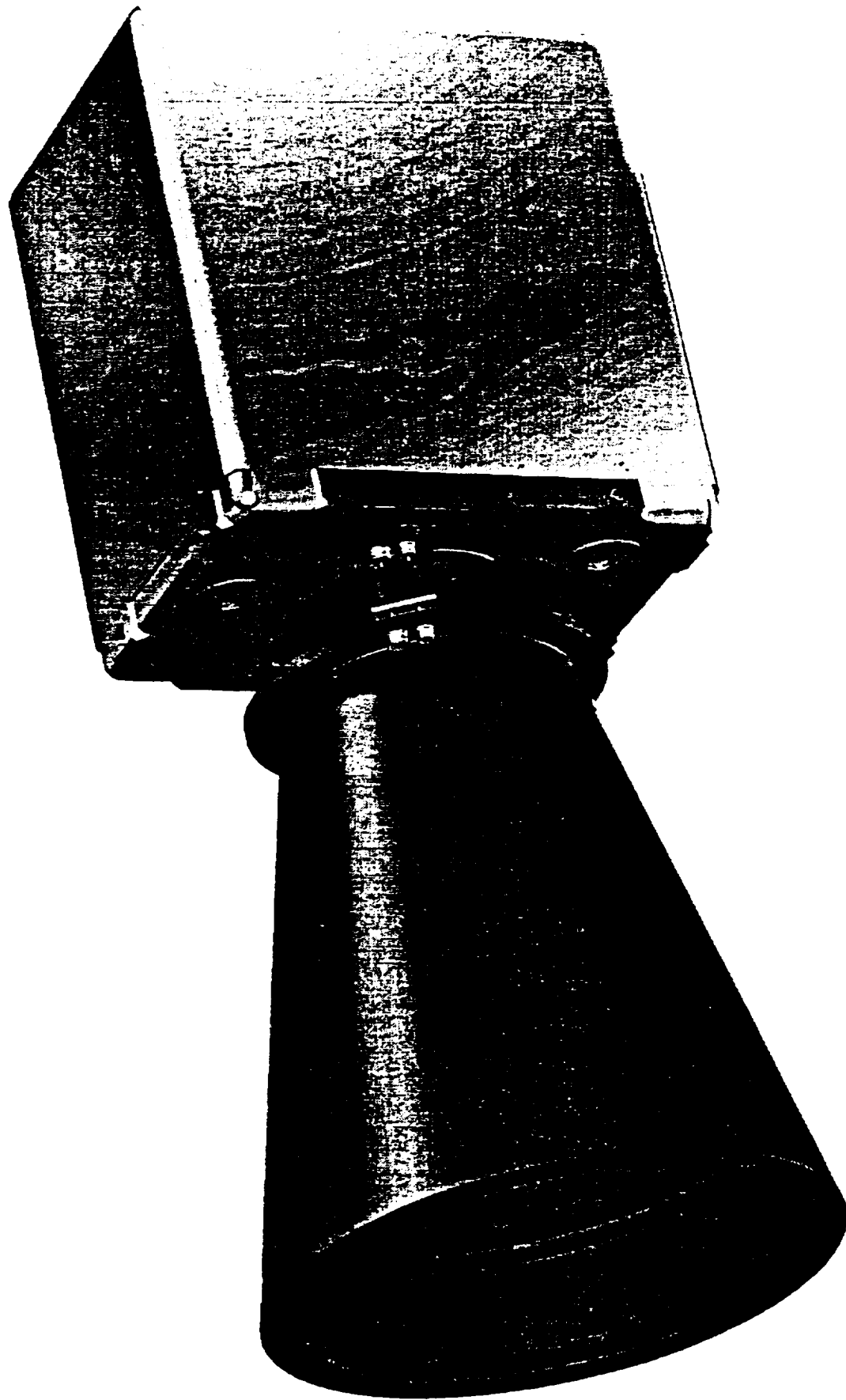
Miniaturized WFOV Star Tracker and Space Qualification of HDOS' HD-1003 Star Tracker

August 8, 1996

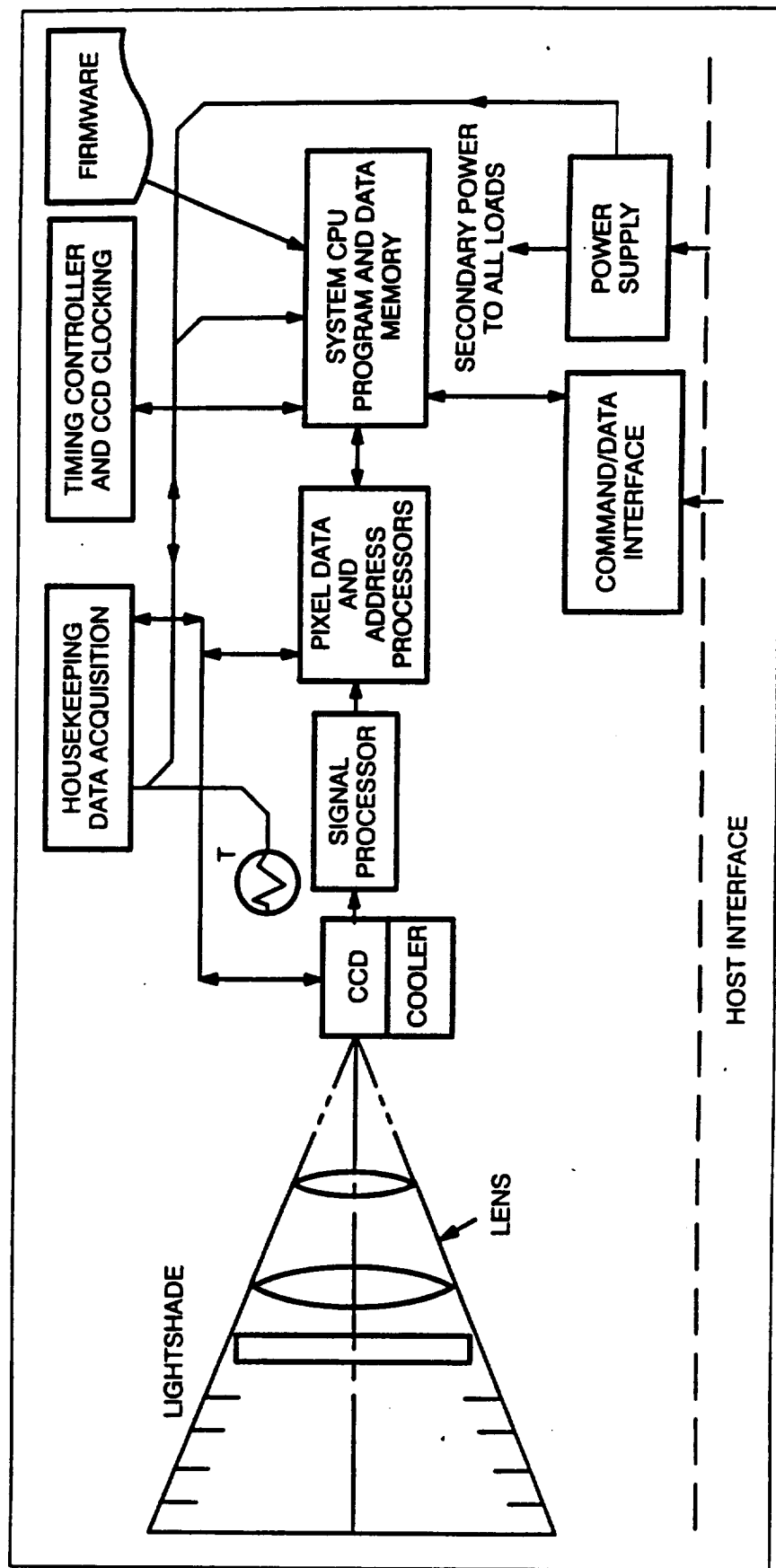
**Presented By:
Al Gauthier
Hughes Danbury Optical Systems, Inc.**

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HD-1003 Star Tracker



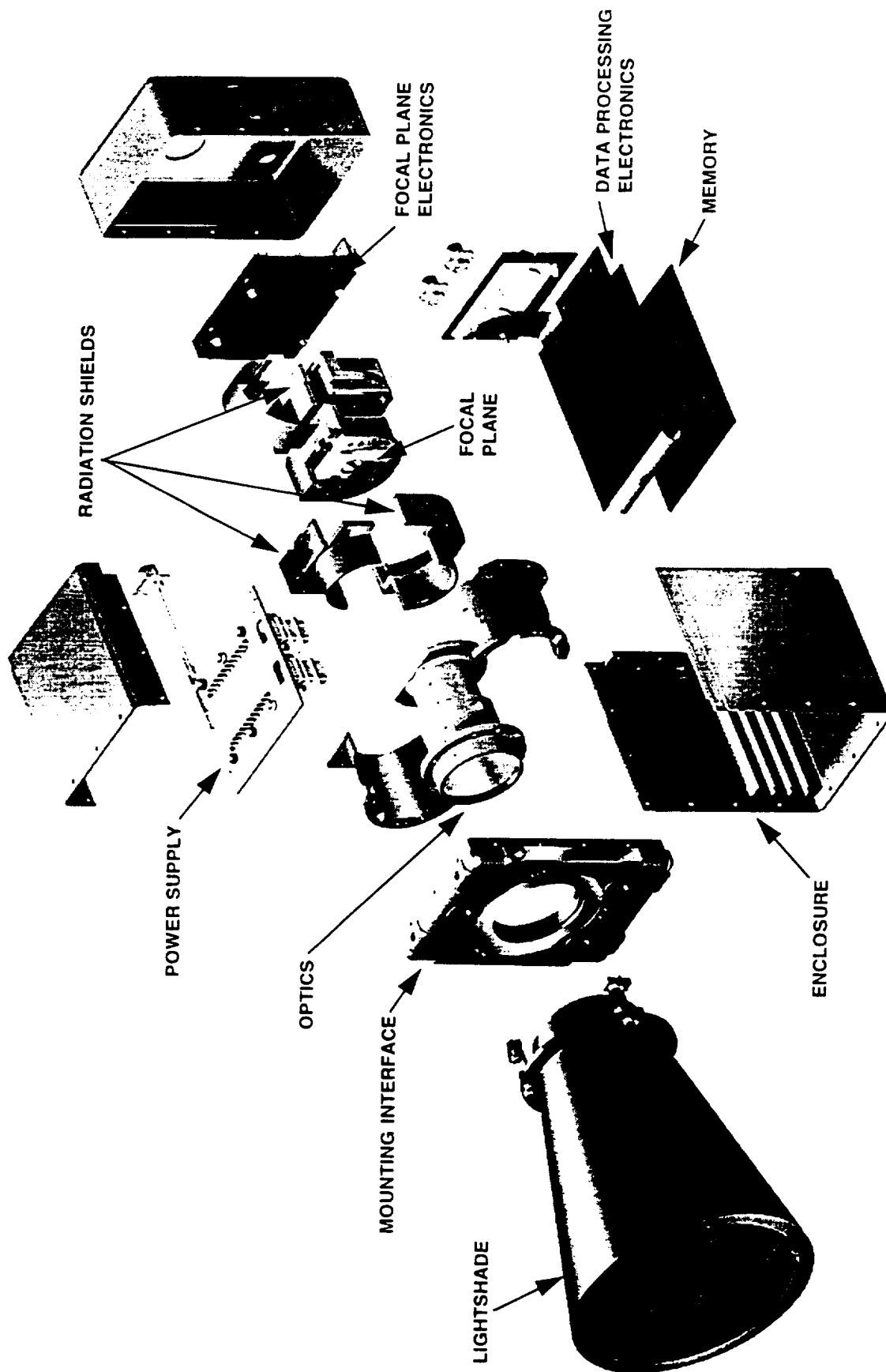
HD-1003 Block Diagram



HD-1003 Performance Requirements

Performance Category	HD-1003 Narrow FOV	HD-1003 Wide FOV
Size (with lightshade) (in. L × in. H × in. W)	16 × 6.2 × 4.4	7 × 6.2 × 4.4
Weight (with lightshade) (lb)	8.0	7.1
Power (average at 28 V dc) (watts)	9	9
Communications Interface	MIL-STD-1553B	MIL-STD-1553B
Field of View (deg)	8 × 8	20 circular
Sensitivity (mV)	+6.0	+4.7
Overall Accuracy, Each Axis		
• Pitch/Yaw (per star) (arc-sec, rms)	6	30
• Multi-star average (arc-sec, rms)	2	10
• Roll (5-stars) (arc-sec, rms)	40	50
• Magnitude (±)	0.25	0.25
Update (frame) Rate (Hz)	10	4
Stars Simultaneously Tracked	6	6
Bright Object Rejection Angle*		
• Sun (deg)	35	40
• Earth (deg)	25	30
• Moon (deg)	25	25
Acquisition Time (6 stars) (sec, 1-sigma)	6	6
Mean Time Between Failures (Hours)	1 × 10 ⁶	1 × 10 ⁶
Environments:		
Temperature		
• Nominal (°C)	-5 to +45	-5 to +45
• Survival (°C)	-15 to +55	-15 to +55
Vibration (Random) (g rms)	14.14	14.14
EMC Level	MIL-STD-461C	MIL-STD-461C
*Lightshade is modular to accommodate various mission requirements.		

Star Tracker (Exploded View)



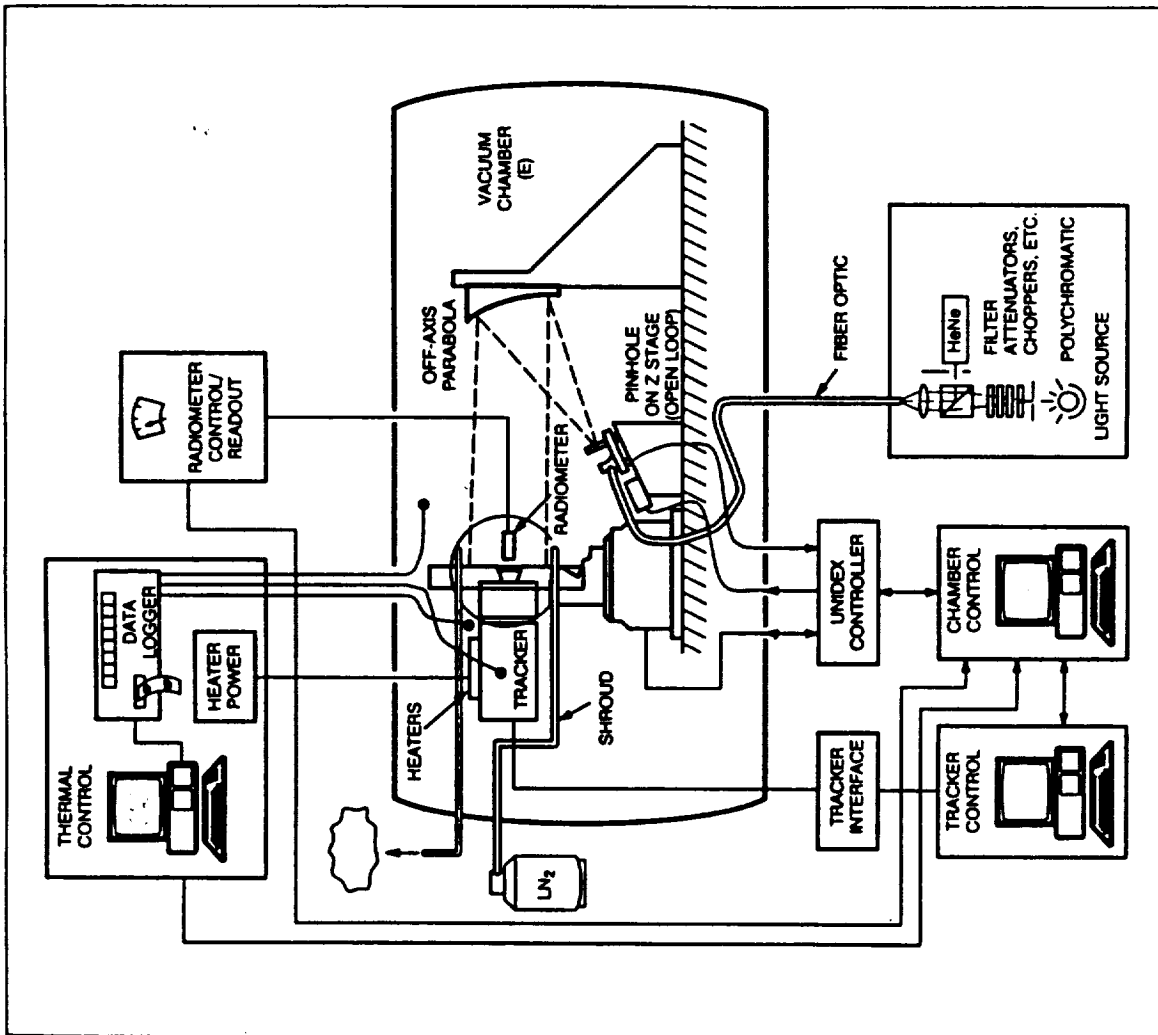
HD-1003 Qualification Test Sequence

Test ID	Environment	Levels	Comments
Continuity/Isolation	Ambient	—	Passed
Calibration Tests	Ambient	$+1.0 \leq m_v \leq +6.0$	Determines stored calibration data
Performance Baseline	Ambient	$+1.0 \leq m_v \leq +6.0$	2 – 4 arc-sec, RMS
Vibration (Random)	Ambient	14.14 Grms 3 axes, 60 sec	Passed
Continuity/Isolation	Ambient	—	Passed
Thermal Vacuum Cycling	10^{-5} torr	-15°C to $+55^{\circ}\text{C}$	2 – 4 arc-sec, RMS
Final Performance	Ambient	$+1.0 \leq m_v \leq +6.0$	2 – 4 arc-sec, RMS
Continuity/Isolation	Ambient	—	Passed
Multi-Star Test	Ambient	—	6 star tracking Simulated proton background
EMI/EMC Test	Ambient	MIL-STD-461C	In – progress

HD-1003 Performance Test Facility

STATION SIMULATION CAPABILITIES

STAR SIMULATOR	
Color Temperature	3,000 to 8,000 K
Magnitude Range	mV = 6.6 to -1.0
Radiometry	Traceable to NBS
TEST COLLIMATOR	
Wavefront Quality	1/4 wave or better
X, Y, Z Controls	Motorized, computer controlled
VACUUM CHAMBER	
Vacuum	1 x 10 ⁻⁶ or better
Chamber Temperature Range	Better than required -34 to +70°C
Temperature Setpoint Stability	Better than ± 0.5°C
2-AXIS GIMBAL	
Resolution	0.1 arc-sec
Accuracy	± 2.0 arc-sec ^a
Orthogonality	± 3.0 arc-sec ^a
LOS Slew Rates (both axes)	0.1 to 1.0 deg/sec commandable in 0.01 deg increments
Servo Controlled	Commandable from its own controller or from GTU computer macros
Position Data Rate	Up to 1 kHz
^a These may be calibrated to approach the resolution accuracy.	



Demonstrated Performance

Performance Parameter	Design Requirements	Demonstrated performance
- Size (Less Lightshade) - Weight (Inc. Lightshade) - Power (at 28 Vdc, Steady State) - Reliability (MTBF) - Radiation Tolerance - Sensitivity - Field of View - Number of Stars / Frame - Update Rate (Frames / Sec) - Accuracy / Star / Axis - mv = +6 - mv = +2 - Sun Rejection Half Angle - Temperature Range - Nominal (°C) - Survival (°C) - Vibration (Grms) - EMC	≤ 200 cu. in. ≤ 8 Lbs. ≤ 12 Watts ≥ 500,000 Hours ≥ 50K Rad - mv ≤ +6 8 x 8 Deg. 6 10 6 arc-sec, 1 Sigma 4 arc-sec, 1 Sigma ≤ 35 Deg. -5 to +45 -20 to +60 12.9 - MIL-STD-461C	191 cu. in. 7.5 Lbs. 8 Watts 1 Million Hours ≥ 100 K Rad - mv ≤ +7 8 x 8 Deg. 6 10 4 arc-sec, 1 Sigma 2 arc-sec, 1 Sigma 30 Deg. -5 to +45 -20 to +60 14.5 - MIL-STD-461C

- **Purpose:** Demonstrate 3-axis all-stellar (attitude & attitude rate) determination & control by a single electro-optical sensor
- **Design:** 20-Degree FOV variation of HD-1003 NFOV (8x8 deg) STA
 - ◆ New Lens Cell using simpler/smaller optical configuration and replacing NFOV's external Shade with internal light baffles
 - ◆ Identical to NSTA's: electronics configuration and envelope w/o Shade (7.04" x 6.2" x 4.35")
- **Mission year #1**, data to be gathered once/day
 - > Stored for ground processing and comparison with attitude and attitude rate info derived from NFOV & other S/C sensors (to evaluate all-stellar capability)
- **Mission year #2 goals are:**
 - ◆ To provide WFOV centroid data to the ACS in order to directly validate single-tracker, all-stellar capability
 - ◆ To evaluate WFOV performance data during unique mission environmental conditions, with excessive stray light, at attitude rates > 0.3 deg/sec, and for time-related trends

Conclusion

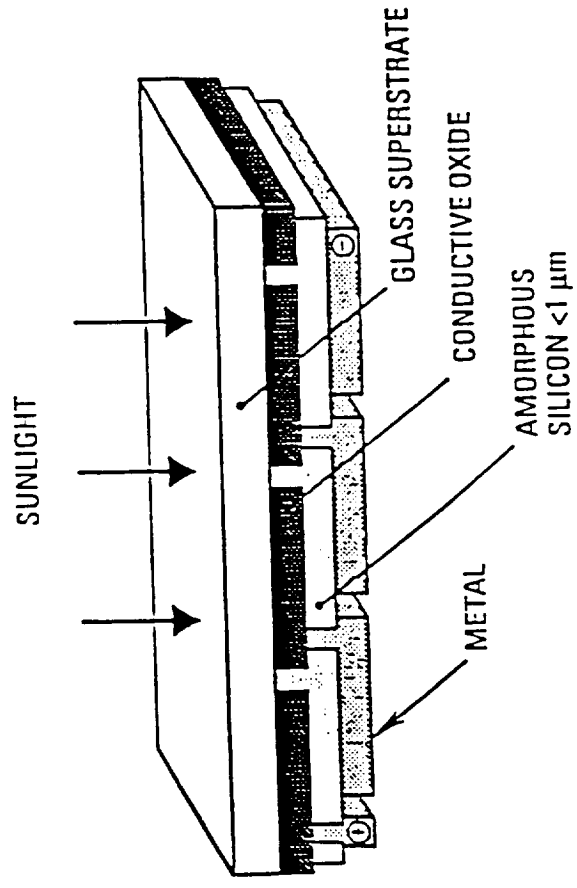
- HD-1003 Design has demonstrated exceptional performance during recent Environmental Test Program
- First Units scheduled to fly on 'Lewis' later this year

SSTI Amorphous Silicon Solar Cell Flight Experiment

G.J. Vendura, Jr.

TRW Space and Electronics Group
One Space Park,
Redondo Beach, California 90278

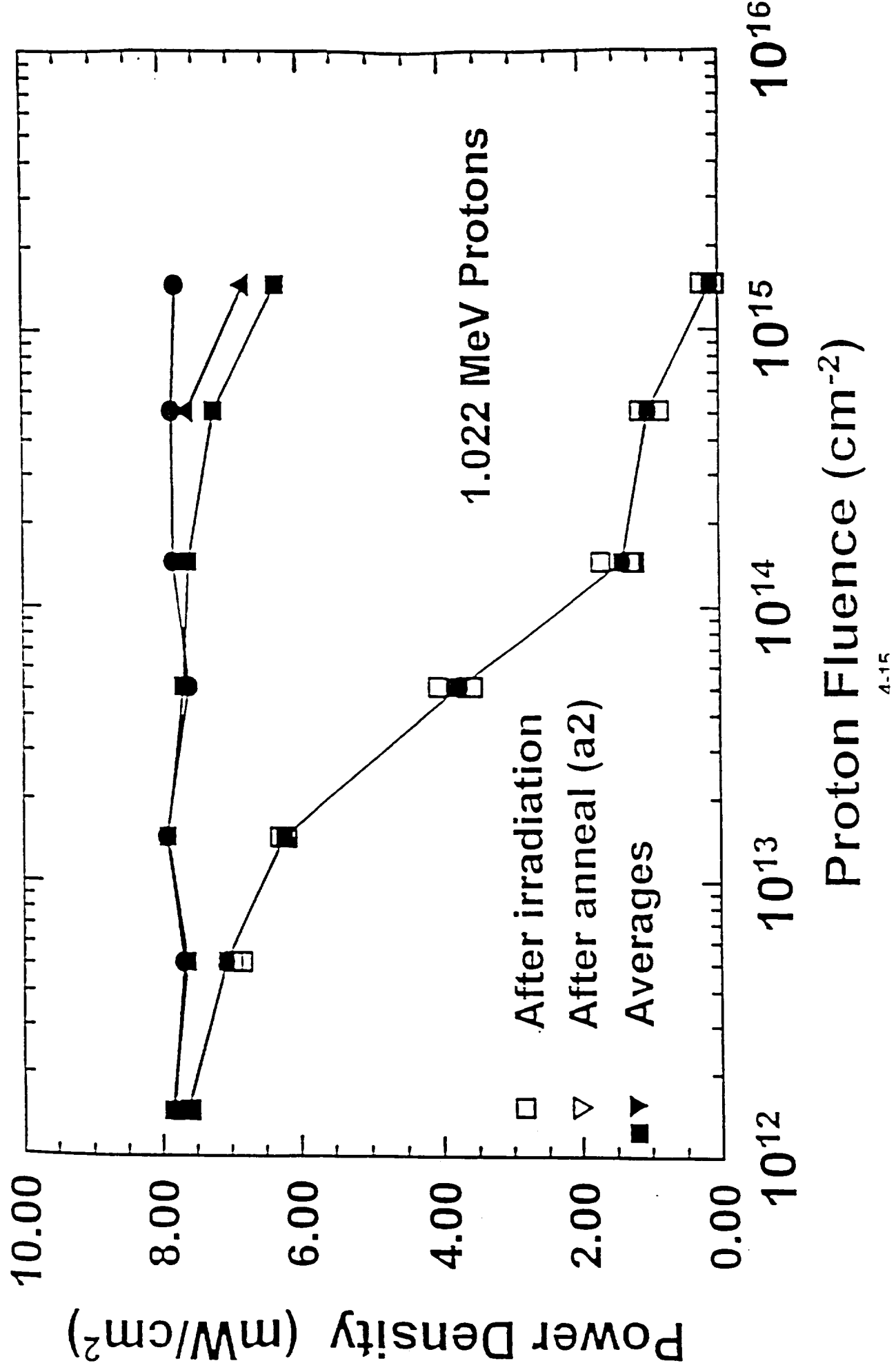
A-SI STRUCTURE



AMORPHOUS SILICON ADVANTAGES

- 1) Very Large Area $\geq 12 \times 13$ in
- 2) Low cost
- 3) Thin
- 4) Flexible
- 5) Low Weight
- 6) Monolithically Interconnectible
- 7) High Radiation Resistance

Anneal Data for Single-Junction a-Si:H Cells



SSTI AMORPHOUS SILICON SOLAR CELL EXPERIMENT

GOALS

- 1) IVs
- 2) Radiation Effects: JPL & WSU Verification & Expansion
- 3) Radiation Degradation / Recovery vs. Temperature
- 4) Photon Stability (Staebler-Wronski Effect)

MATRIX

SSTI Amorphous Silicon Samples

<u>I.D.</u>	<u>Supplier</u>	<u>Quantity</u>	<u>Type</u>	<u>Size (in)</u>	<u>Cover (mil)</u>	<u>Description</u>	<u>Comments</u>
1.	Solarex	1	DJ a-Si	12x13	40	Rigid Module	High Temperature
2.	Solarex	1	DJ a-Si	12x13	40	Rigid Module	Ambient Temperature
3.	Solarex	2	DJ a-Si	3 x 3	44	Flexible Module	2 3 x 3 inch modules in parallel
4.	Solarex	2	DJ a-Si	3 x 3	44	Flexible Module	2 3 x 3 inch modules in parallel
5.	Amonix	9	Point Si	2 x 2 cm	2	Flexible Module	9 2 x 2 cm cells in series
6.	Amonix	9	Point Si	2 x 2 cm	6	Flexible Module	9 2 x 2 cm cells in series

TEMPERATURE GOALS

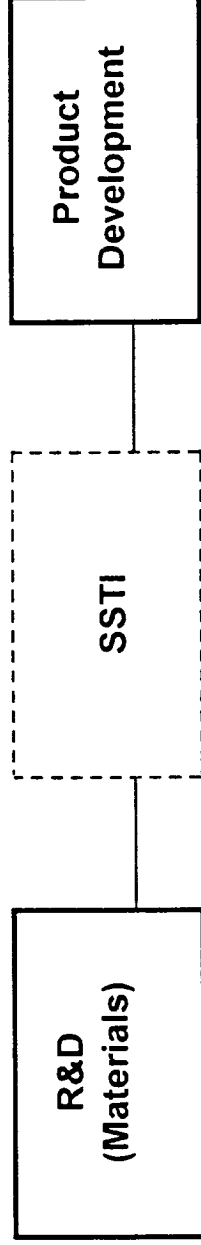
<u>Sample</u>	<u>Temperature</u>	<u>Considerations</u>
Plate 1	ambient	Thermal Design
Plate 2	ambient +	
All Other	ambient	

OPERATION1

<u>Month</u>	<u>Electrical² Measurement</u>	<u>Sun</u>	<u>Eclipse</u>	<u>Total Meas/Day/Sample</u>
1	1Vs	every 10 min	NA	~ 90
	TCs	every 10 min	every 10 min	~ 135
>1	1Vs	once at peak	NA	15
	TCs	once at peak	once at trough	30

- 1 Assumes 58 min (sun) + 37 min (eclipse) = 95 min total period (15 cycles/day)
- 2 Assumes the following are parallely monitored: sun angle, insolation and radiation

AMORPHOUS SILICON PROGRAM EVOLUTION



PRODUCT 1: SSTI PANEL

CELL DEVELOPMENT

- Contacting
- Solderability
- Interconnection
- Stress Release
- Development Testing

PANEL INTEGRATION

- Adhesive M&Ps
- Large Area Issues
- Thermal Designs
- Temperature Monitoring
- Temperature Cycling

POST INTEGRATION TESTING

- Electrical
- Stowage/Deployment
- Acoustic
- Temperature Cycling

CASCADE CELL PANEL

Ed Gaddy
301-286-1338

Jim McGuire
301-286-8822

Goddard Space Flight Center



AGENDA

PURPOSE

TECHNOLOGY DESCRIPTION

COST/SAVINGS

EXPERIMENTAL CELLS

CONCLUSIONS



PURPOSE

- Demonstrate and Monitor High Efficiency Solar Cells
- Increase Payload/Satellite Mass Ratio



TECHNOLOGY DESCRIPTION

- Metal Organic Chemical Vapor Deposition on Germanium Substrate
- More Layers than Ga As /GeCells
 - AL IN P₂ (.3 to .65 microns)
 - Ga As (.65 to .85 microns)
 - Ge (.85 to 1.8 microns)
- Automatic and Quick Cell Growth. However
 - lower yield do to more layers
 - must add by pass diode



TECHNOLOGY DESCRIPTION

- 25.7 Efficiency (National Renewable Energy Laboratory
 - U.S. 18.5% for Ga As/Ge
 - U.S. 14.8% for S:
- Same sizes as for Ga As/Ge
- Same weight as for Ga As/Ge
- Same manufactures as for Ga As/Ge

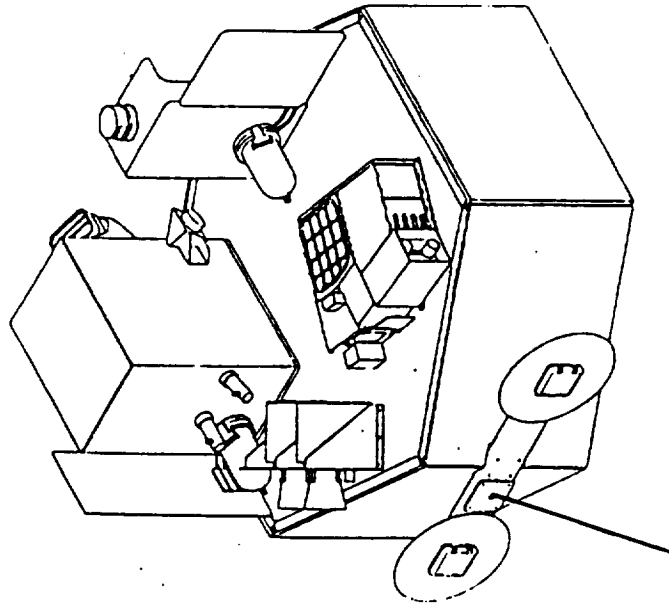
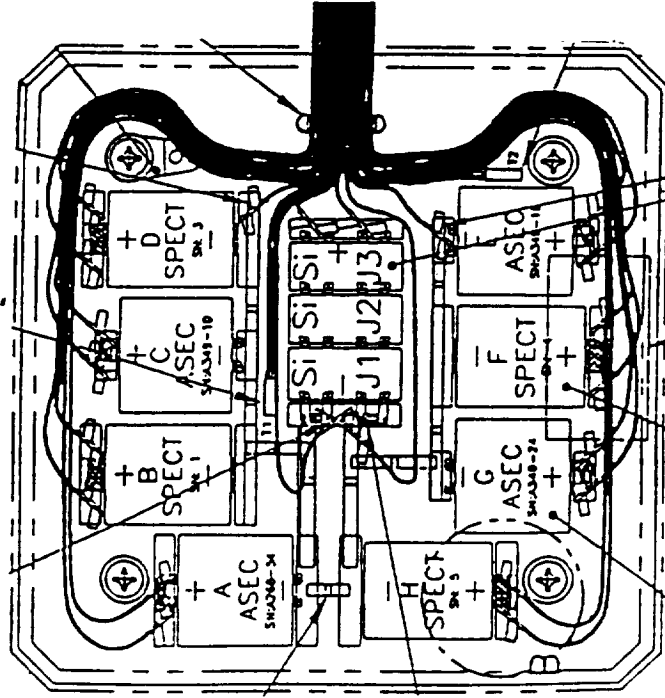


COST/SAVINGS

- 20 % Higher than Ga As/Ge
- Can see up to \$450 k/kg savings



EXPERIMENTAL CELLS



ACSE

Goddard Space Flight Center

July 25, 1996



EXPERIMENTAL CELLS

	<u>Efficiency</u>
• Tecstar A (Dual Junction):	22.2%
• Spectrolab B (Triple Junction):	22.9%
• Tecstar C (Dual Junction):	22.3%
• Spectrolab D (Triple Junction):	22.8%
• Tecstar E (Dual Junction):	22.3%
• Spectrolab F (Triple Junction):	22.9%
• Tecstar G (Dual Junction):	22.6%
• Spectrolab H (Triple Junction):	22.7%



CONCLUSIONS

- 30 % Reduction in Solar Arrays
- Smaller Arrays result in dynamically stiffer Arrays
- Smaller Arrays mean less deployment complexity
- Smaller Arrays mean less drag less fuel
- Smaller Arrays mean smaller buss; More Payload

Spaceborne Global Positioning System (GPS) Technology

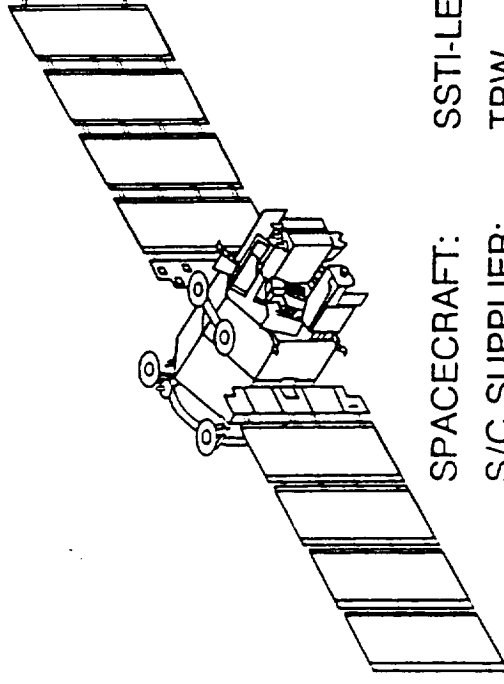
*SSTI-Lewis Workshop
August 8, 1996*

**Frank H. Bauer
NASA GSFC
Guidance, Navigation and Control Branch
frank.bauer@gsfc.nasa.gov**

GPS ATTITUDE DETERMINATION FLYER (GADFLY) EXPERIMENT

EXPERIMENT OBJECTIVES

- DEMONSTRATE AND VALIDATE COST-SAVING, SYSTEMS ENGINEERING FEATURES THAT CAN BE EXPLOITED USING GPS IN SPACECRAFT
- VALIDATE GPS ATTITUDE SENSING IN SPACE USING FLIGHT QUALIFIED GPS RECEIVER
- QUANTIFY STATIC AND DYNAMIC ATTITUDE ERROR SOURCES USING SPACECRAFT STAR TRACKER AND OTHER SENSORS AS A MEASUREMENT FIDUCIAL
- DETERMINE EFFECTS AND IMPACTS OF VEHICLE MULTIPATH
- PROVIDE AUTONOMOUS ORBIT DETERMINATION SERVICE TO SPACECRAFT
- PROVIDE PRECISE TIME REFERENCE TO SPACECRAFT



SPACECRAFT:

SSTI-LEWIS

S/C SUPPLIER:

TRW

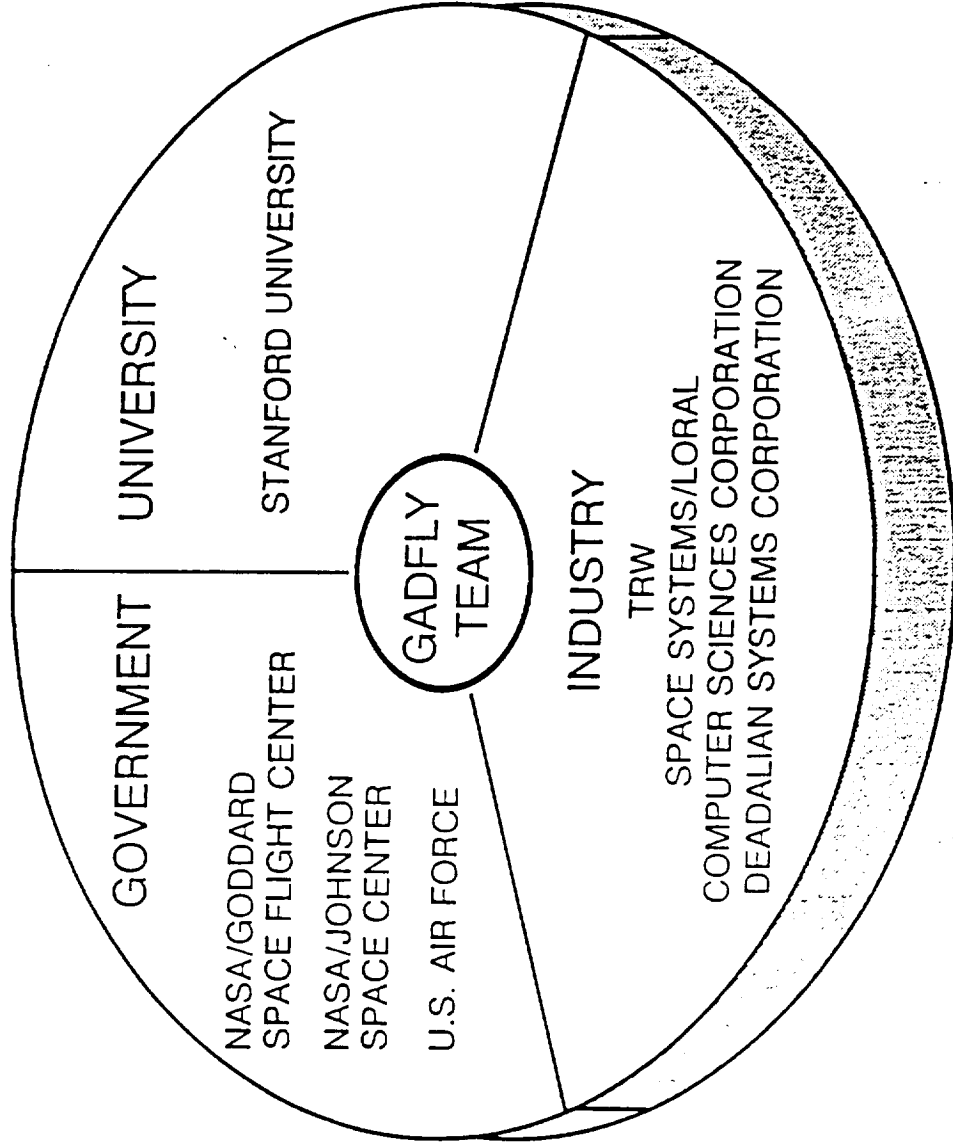
LAUNCH:

JULY 1996

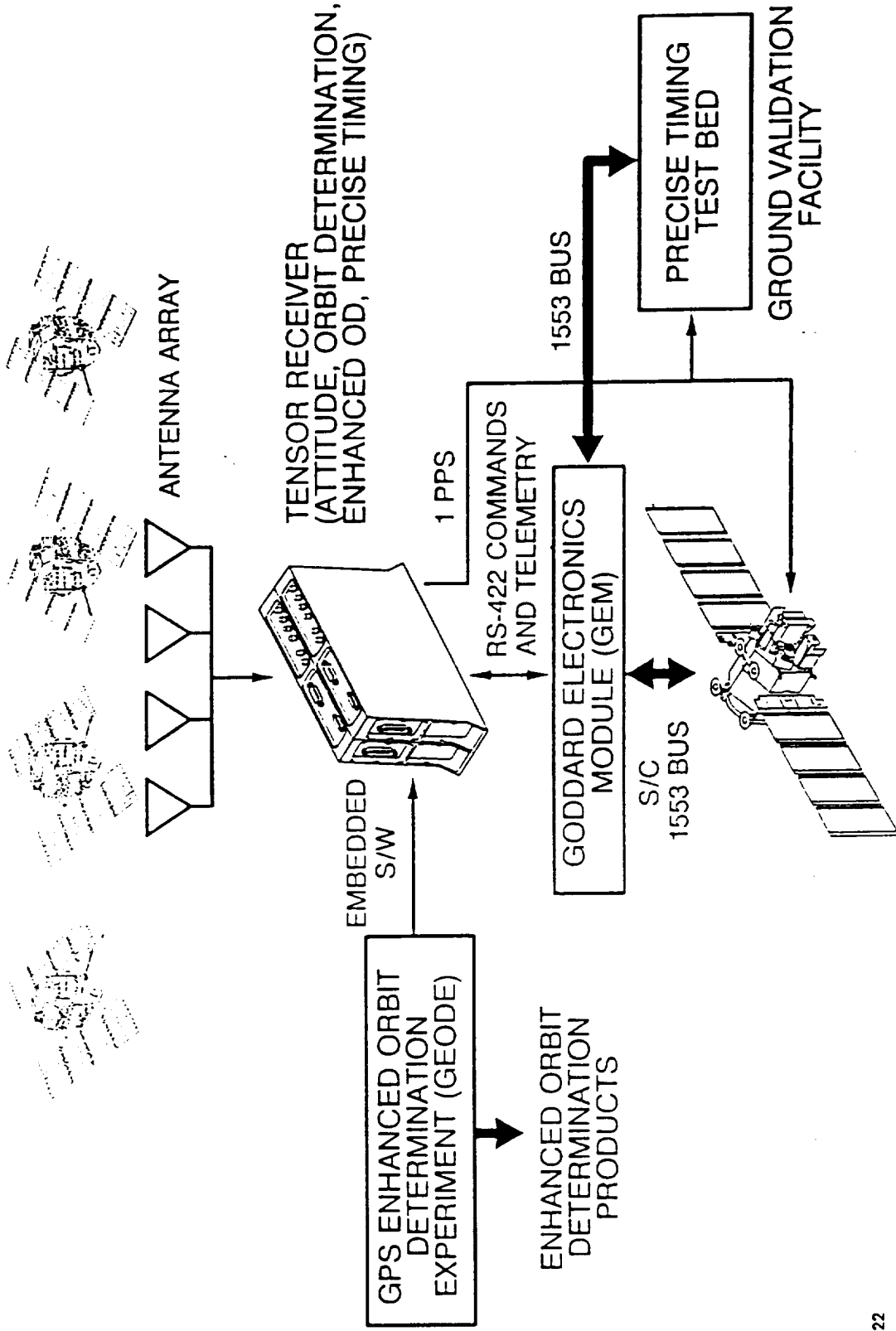
LAUNCH VEHICLE:

LOCKHEED
LAUNCH
VEHICLE

GADFLY TEAM MEMBERS

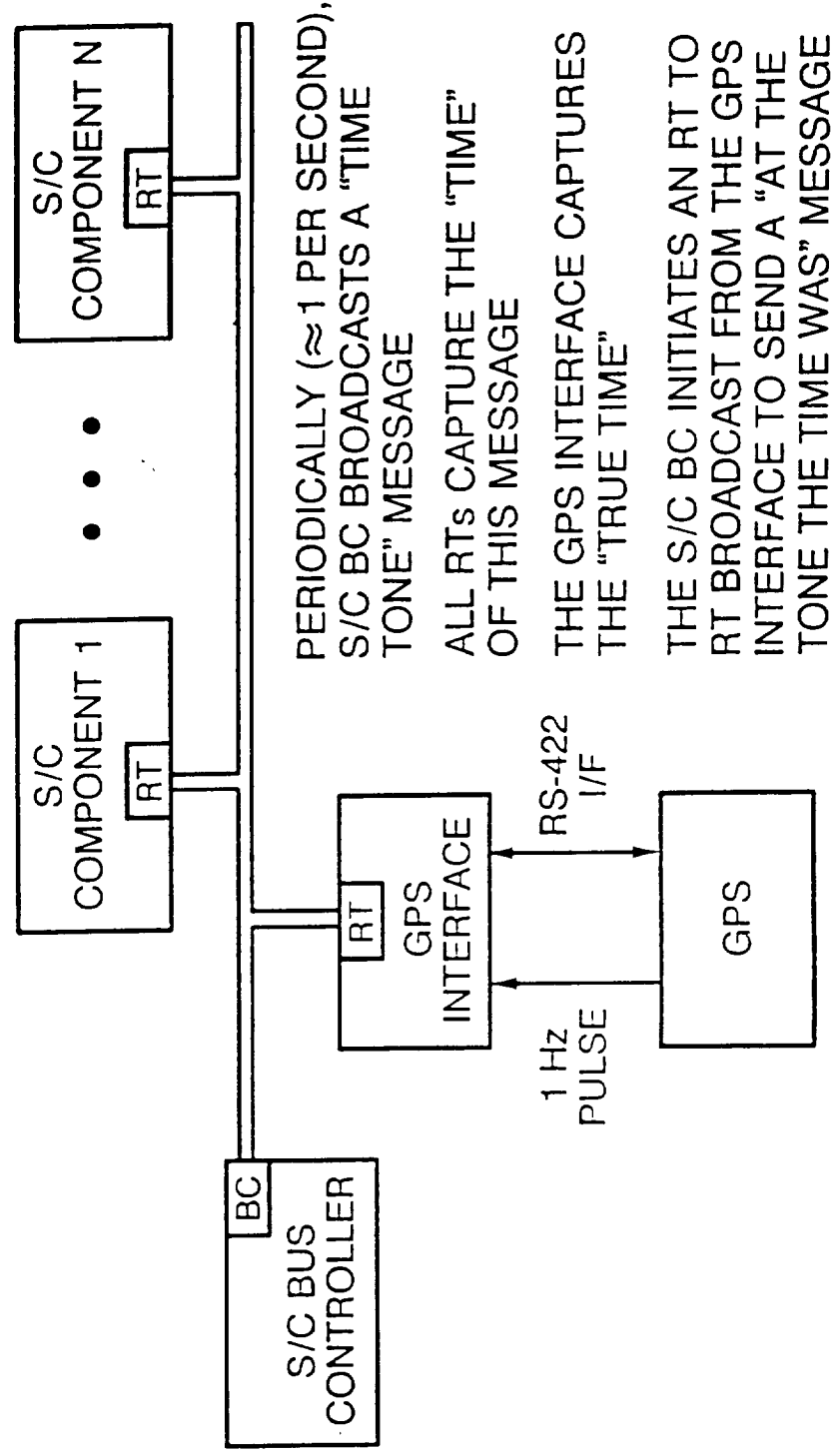


GADFLY SYSTEMS CONFIGURATION



E938.022

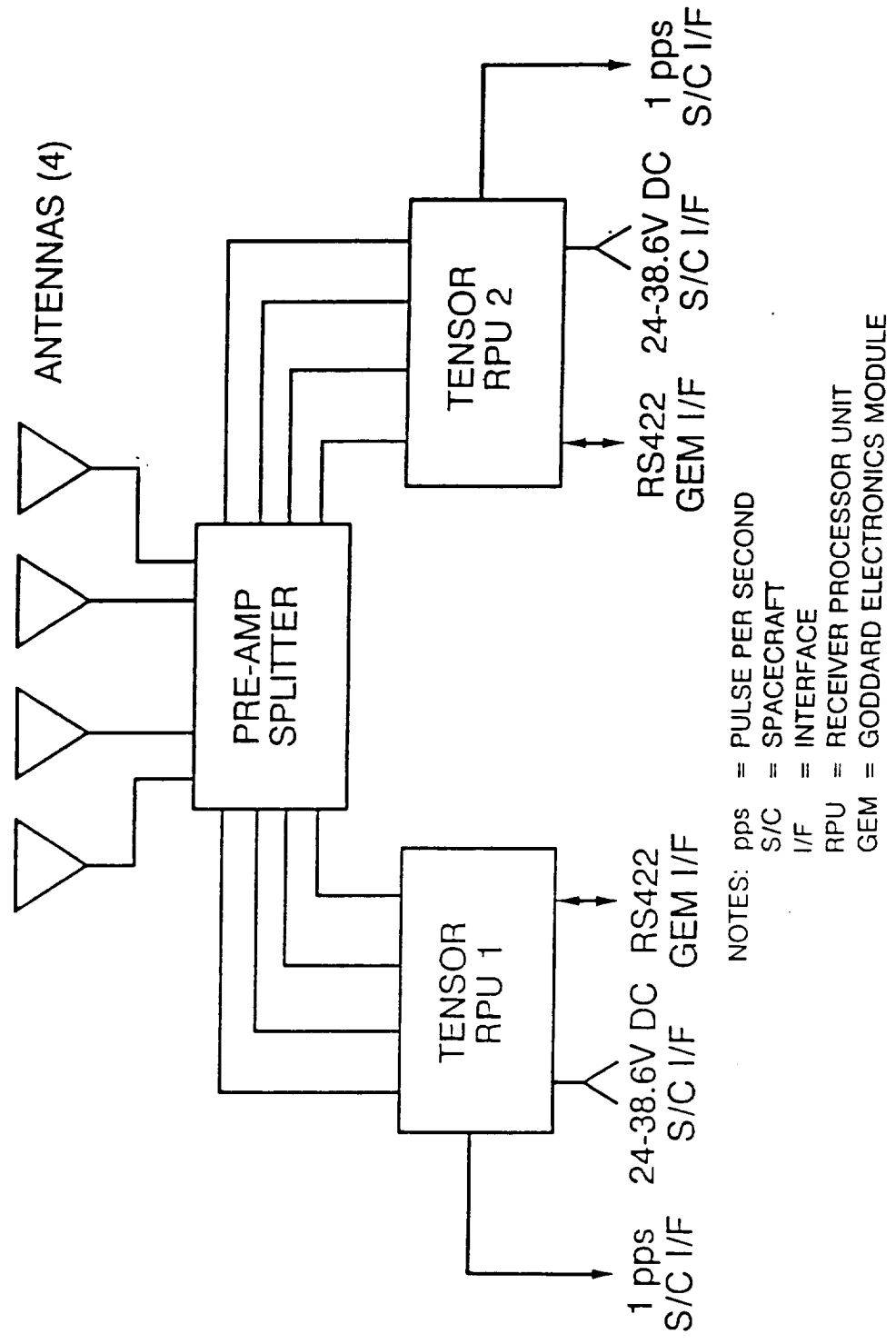
TIME DISTRIBUTION



GADFLY PERFORMANCE GOALS

	SPACECRAFT REQUIREMENTS	GADFLY GOALS
ATTITUDE DETERMINATION	NONE (USING GPS)	0.45° 3 σ
ORBIT DETERMINATION	150 m 3 σ IN-TRACK 150 m 3 σ CROSS-TRACK 230 m 3 σ RADIAL TIME TAGS: 2 msec, 1Hz UPDATE	450 m 3 σ UNFILTERED 150 m 3 σ TENSOR FILTERED 60 m 3 σ GEODE TIME TAGS: <1 msec 1Hz UPDATE
PRECISE TIMING REFERENCE	1 msec, 1 Hz UPDATE	TIME TAGS: <1 msec DISCRETE PULSE: <1 μ sec

GADFLY HARDWARE BLOCK DIAGRAM



TENSOR RECEIVER PROCESSOR UNIT (QUANTITY: 2)

- SPACE SYSTEMS/LORAL (SS/L) PART NUMBER: E034580

- EXTERNAL FINISH:

- MOUNTING SURFACE CONTACT AREA:
CHEM FILM PER MIL-C-5541, CLASS 3

- EXTERIOR SURFACES: BLACK CHEMGLAZE
Z306 PAINT

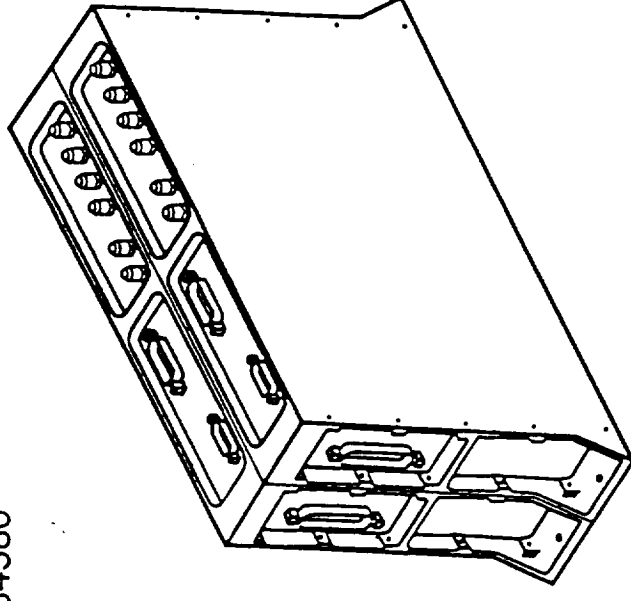
- THERMAL CONTROL EMISSIVITY: 0.9

- THERMAL DISSIPATION: 14.0 WATTS, AVERAGE

- UNIT WEIGHT: 8.9 LBS

- DIMENSIONS: 3.15 x 10.83 x 7.05 IN

- MOUNTING SURFACE CONTACT AREA: 34 SQ. IN.



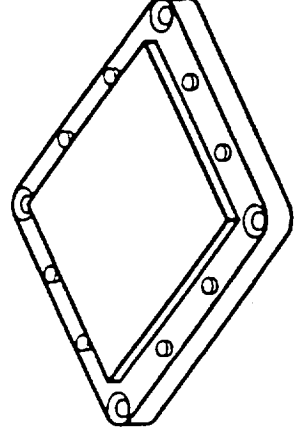
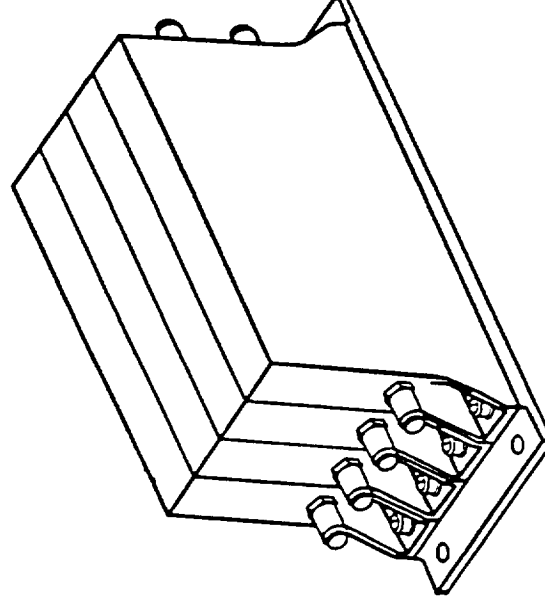
TENSOR HARDWARE PHYSICAL CHARACTERISTICS

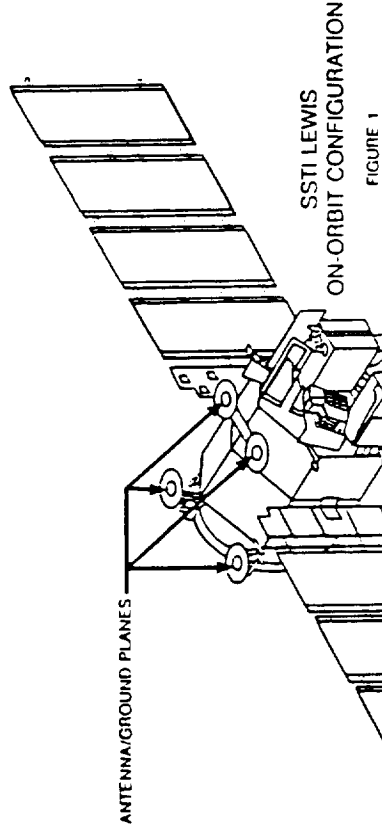
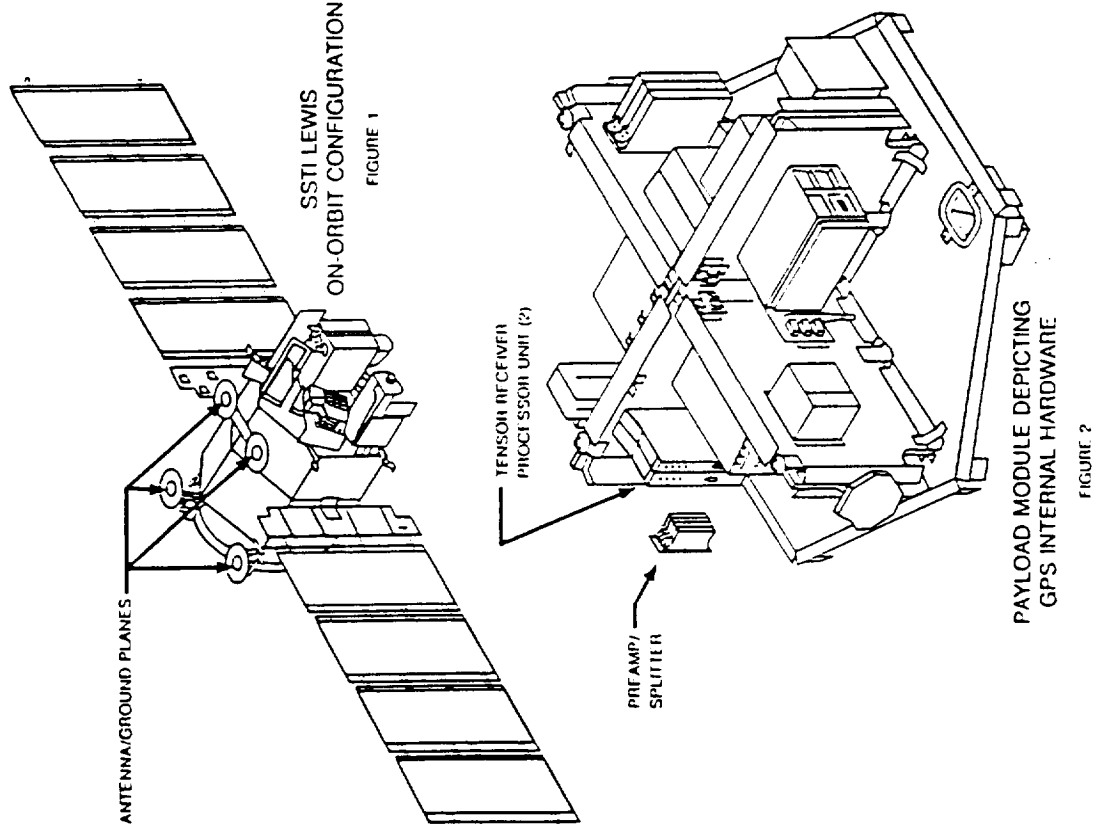
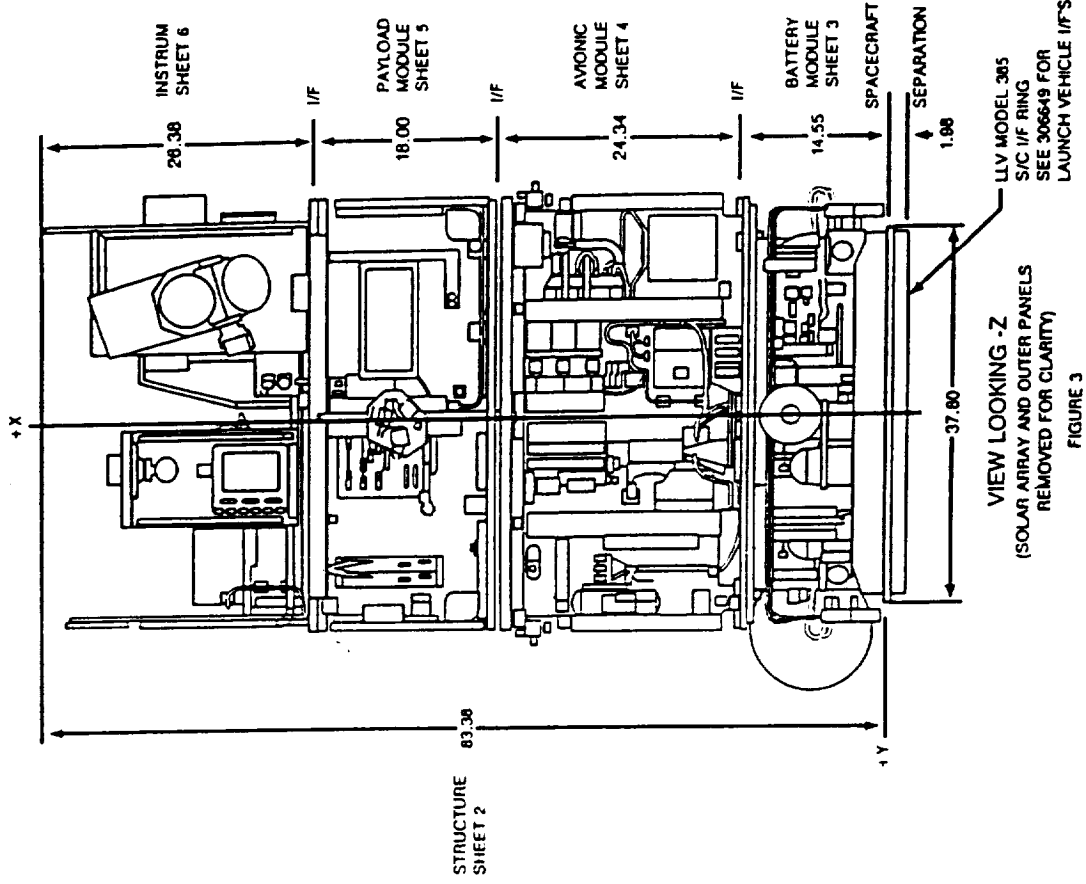
FOUR CHANNEL PREAMPLIFIER/SPLITTER

- THERMAL DISSIPATION: 1.0 WATT, ORBIT AVERAGE
- UNIT WEIGHT 0.9 LBS.
- DIMENSIONS: 2.00 x 5.43 x 3.01 IN.
- MOUNTING SURFACE CONTACT AREA: 4.6 SQ. IN

GPS ANTENNA (1 OF 4)

- BALL GPS ANTENNA PART NUMBER 301700-500
- ELECTRICAL SPECIFICATIONS:
 - FREQUENCY: 1573.4 - 1577.4 MHz
 - VSWR: 2.0:1.0
 - GAIN (AS MEASURED ON 16 INCH GROUND PLANE): 4.5 dBi
 - AZIMUTH COVERAGE: OMNI-DIRECTIONAL
 - ELEVATION COVERAGE: HEMISPHERICAL
 - POLARIZATION: RIGHT HAND CIRCULAR
- THERMAL DISSIPATION: 0 WATTS
- UNIT WEIGHT: 0.20 LBS
- DIMENSIONS: 2.87 x 2.87 x 0.34 IN.





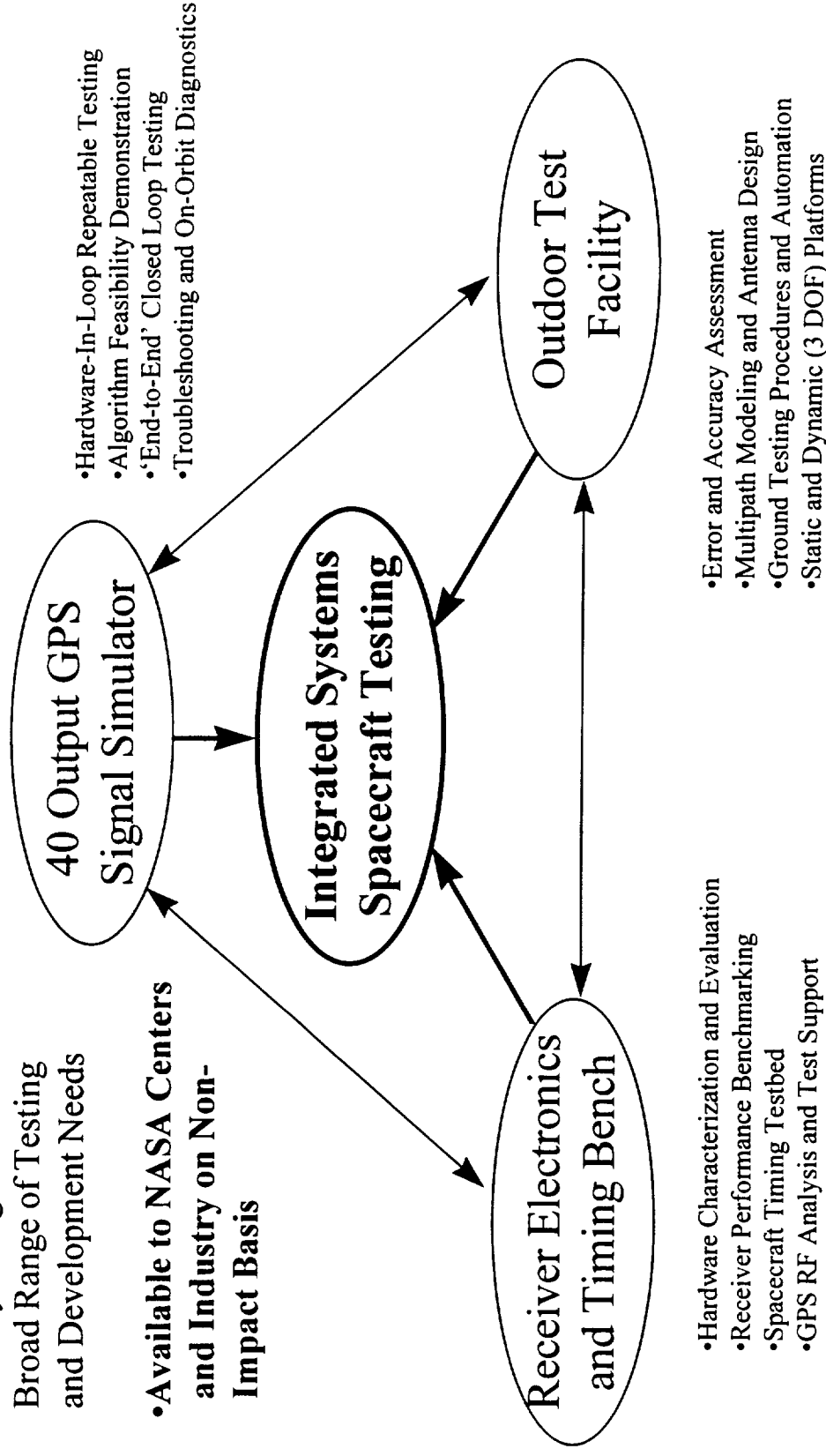
E938.001

Spaceborne GPS Preflight Testing

- **Environmental testing**
 - Thermal Vacuum
 - Vibration
 - EMI
- **Functional, performance and phasing tests**
 - Aliveness testing using GPS generator
 - On-orbit performance characterization using simulator
 - End-to-end phasing tests for closed loop control experiments
- **Sensor calibration and alignment**
 - Self survey/alignment
 - Line bias estimation

GPS Test Facility At GSFC

- Facility Designed to Suit Broad Range of Testing and Development Needs
- Available to NASA Centers and Industry on Non-Impact Basis



Testing Consultation

- **NASA GSFC has established itself as a leader in the integration and testing of GPS on spaceborne vehicles**
- **Organizations who wish to integrate this technology on their spacecraft can contact the NASA Goddard Team for support**
- **Prime points of contacts:**
 - Frank H. Bauer, 301-286-8496, frank.bauer@gsfc.nasa.gov
 - E. Glenn Lightsey, 301-286-6093, glenn.lightsey@gsfc.nasa.gov



Structural Loads & Acoustics Measurements (SLAM)

Kirsten J. Kirkman
Mechanical Engineering Branch
NASA/Goddard Space Flight Center



Agenda

- ❖ Introduction
- ❖ Background
- ❖ Objectives
- ❖ Plans for SLAM Data
- ❖ Benefits of SLAM
- ❖ Conclusions



Introduction

- ❖ Design and test loads for spacecraft are determined by transient coupled loads analyses with the launch vehicle.
- ❖ Flight data on the spacecraft side of the vehicle interface will help to correlate spacecraft flight responses with coupled loads analyses predictions.



Data Acquisition Background

- ❖ *Payload & vehicle* launch and landing environment data obtained from Space Shuttles.
- ❖ *Vehicle* launch environment data obtained from Expendable Launch Vehicles (ELV's).



SLAM Objectives

- ❖ Obtain flight measurements of the spacecraft response to the ELV launch environment.
- ❖ Verify the accuracy (conservatism) of flight coupled loads analyses routinely performed by the launch vehicle contractor.
- ❖ Use data to help characterize the launch loads on future ELV launched spacecraft.
- ❖ Optimize the design of future spacecraft.



Present Missions

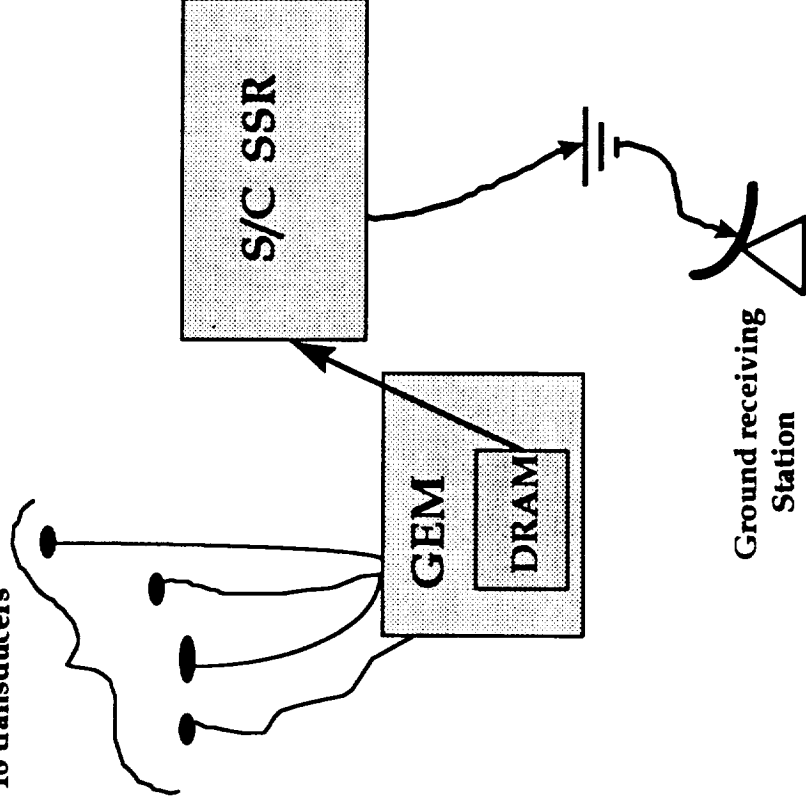
- ❖ SSTI - Lewis spacecraft
 - Lockheed Launch Vehicle (LMLV I) - Dec 1996.
- ❖ The Advance Composition Explorer (ACE) spacecraft
 - Delta II launch vehicle - August 1997.



SLAM Description

18 transducers

- ❖ 18 Transducers
 - 9 low frequency accels.
 - 6 high frequency accels.
 - 3 microphones
- ❖ 450 seconds of data
- ❖ Major launch events include:
 - Max dynamic pressure
 - Stage 1 ignition
 - Stage 1 separation
 - Stage 2 ignition
 - Satellite Deployment





Plans for SLAM Data

- ❖ Have Lockheed-Martin perform a reconstruction coupled loads analysis.
 - Recreate the actual launch day flight.
- ❖ Convert SLAM measured data into a comparable format.

Perform verification of Finite Element prediction technique:

- Correlate the modified coupled flight loads analysis with SLAM's measured results.



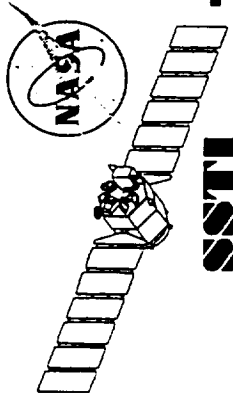
Benefits of SLAM Analysis

- ❖ Validate the accuracy of the coupled loads analysis techniques employed by launch vehicle contractors.
- ❖ Provide a better database for the acoustic environment.
- ❖ Build a database for various launch vehicles:
 - Group the data so that the number of zones for a particular launch vehicle listed in GEV's can be increased and updated.
- ❖ Provide a more efficient way to optimize designs without over designing.



Conclusions

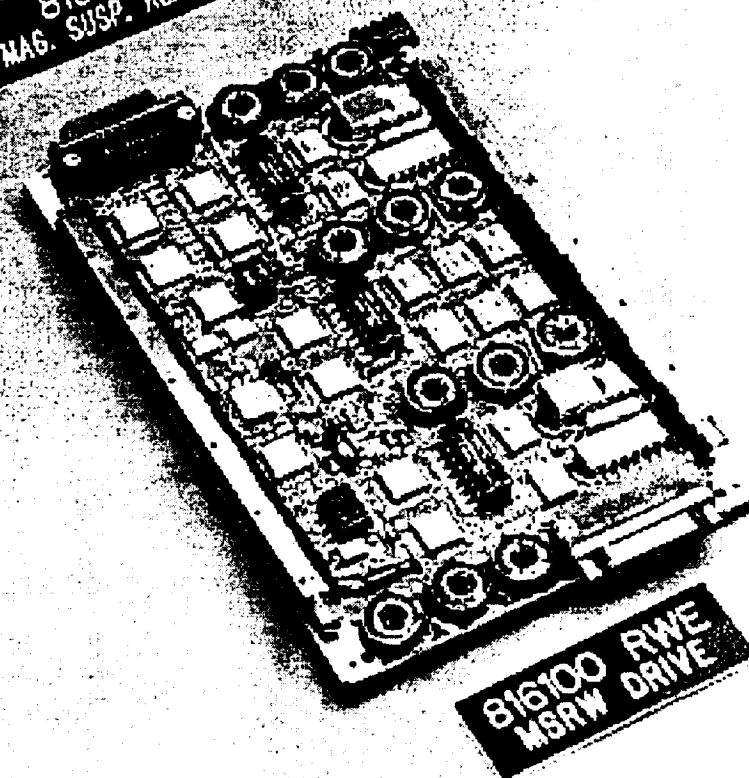
- ❖ Once a database of launch loads exists, the data will be used to optimize future spacecraft structures.
 - Reduce Loads
 - Reduce Weight
 - Reduce Cost
- ❖ The present SLAM package is a protoflight system.
 - Through optimization, future SLAM packages will become cheaper and faster.

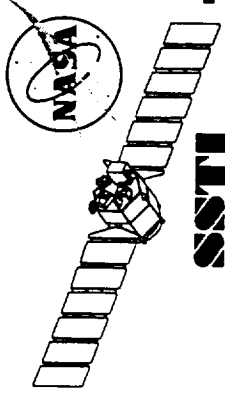


Magnetically Suspended Reaction Wheel

Martin Beck

August 8, 1996

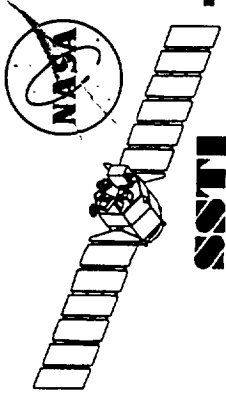




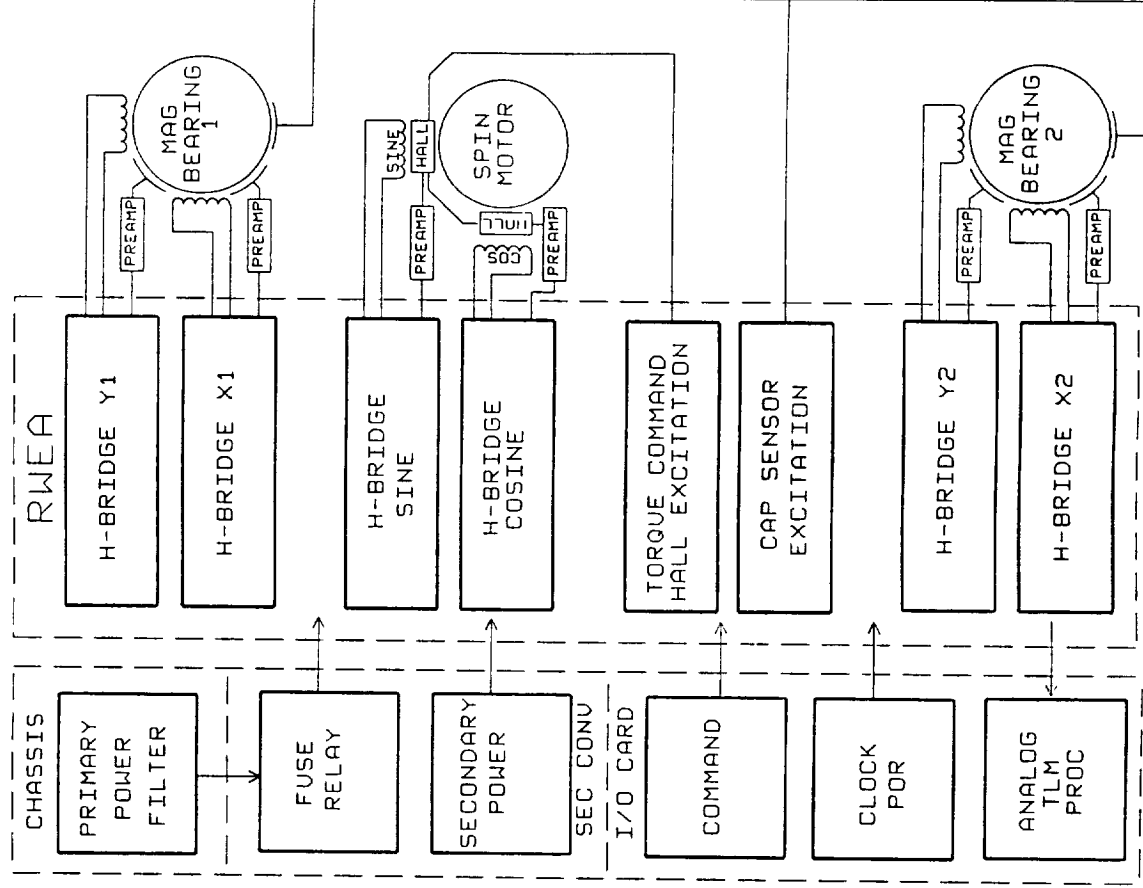
Magnetically Suspended Reaction Wheel Assembly Top Level Requirements

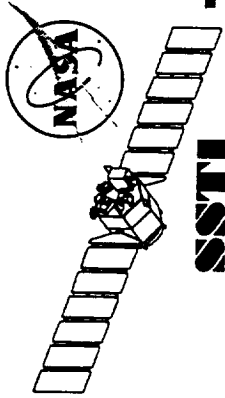


- Existing Unit, Developed On BP/AITP, To Be Refurbished For SSTI
- Independent Technology Demonstration - Magnetic Bearing Reaction Wheel
- Demonstrate Operation Of MSRWA In Space Environment
- Key Features Of MSRWA Compared To Current State Of Practice:
 - Lower Mass, More Compact Unit For Equivalent Function
 - Longer Life Due To Absence Of Bearing Wear/Lubrication
 - Lower Induced Disturbance (Jitter)
- Conventional Mechanical Reaction/Momentum Wheels Have A Maximum Speed Range Of 4000-6000 RPM
- MSRWA Goal Is At Least 15,000 RPM
- Lifetime Objective Of MSRWA >18 Years, Compared To <12 (3-7) Years For Reaction Wheel (Momentum Wheel) Operation

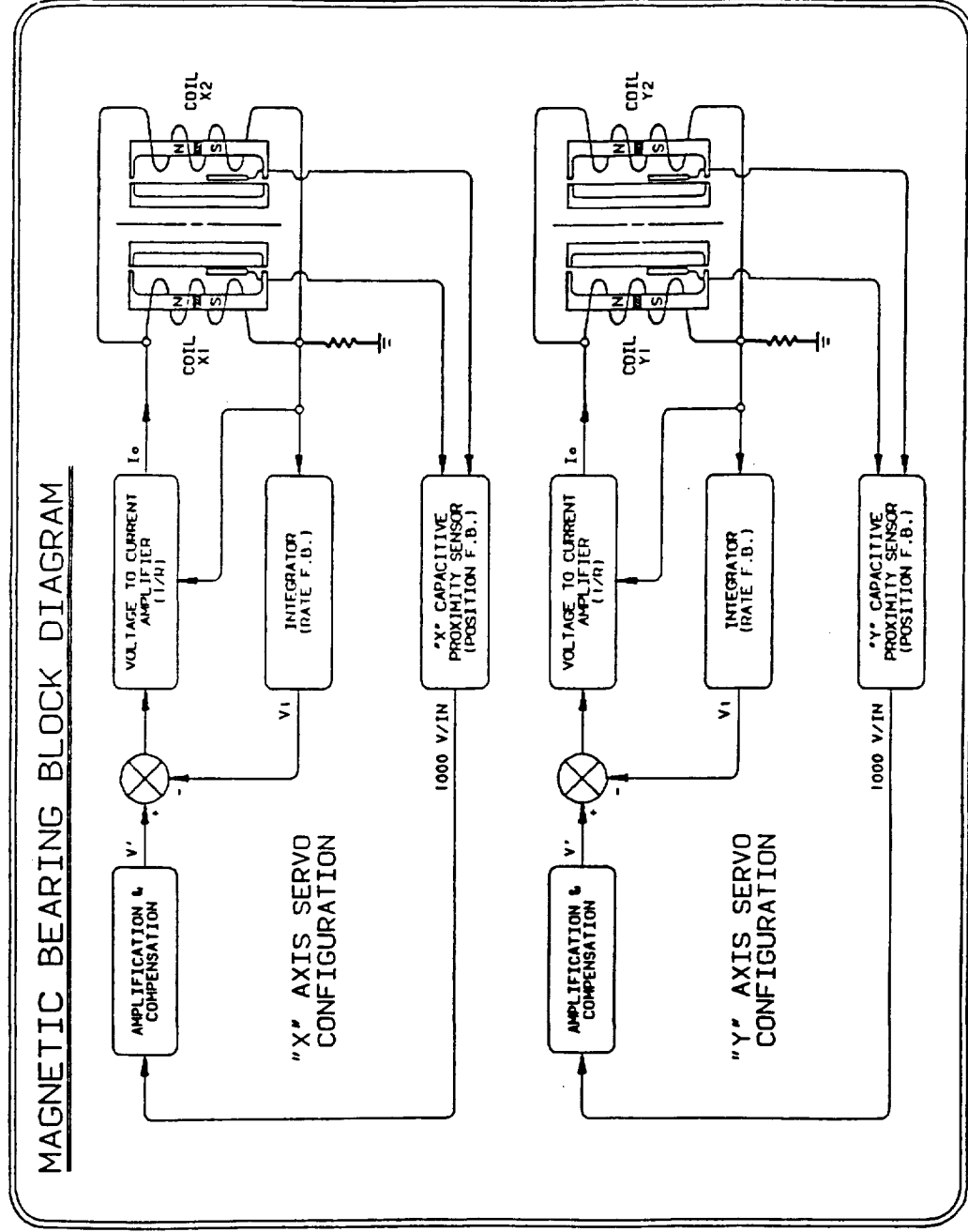


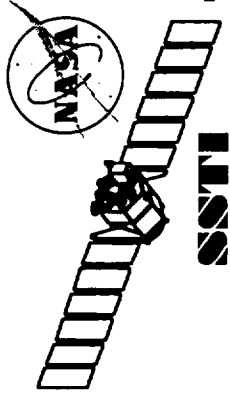
Magnetically Suspended Reaction Wheel Assembly Physical Block Diagram





Magnetically Suspended Reaction Wheel Assembly Mag. Bearing Block Diagram



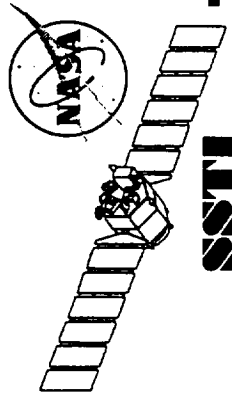


Magnetically Suspended Reaction Wheel Assembly Requirements Vs. Capabilities

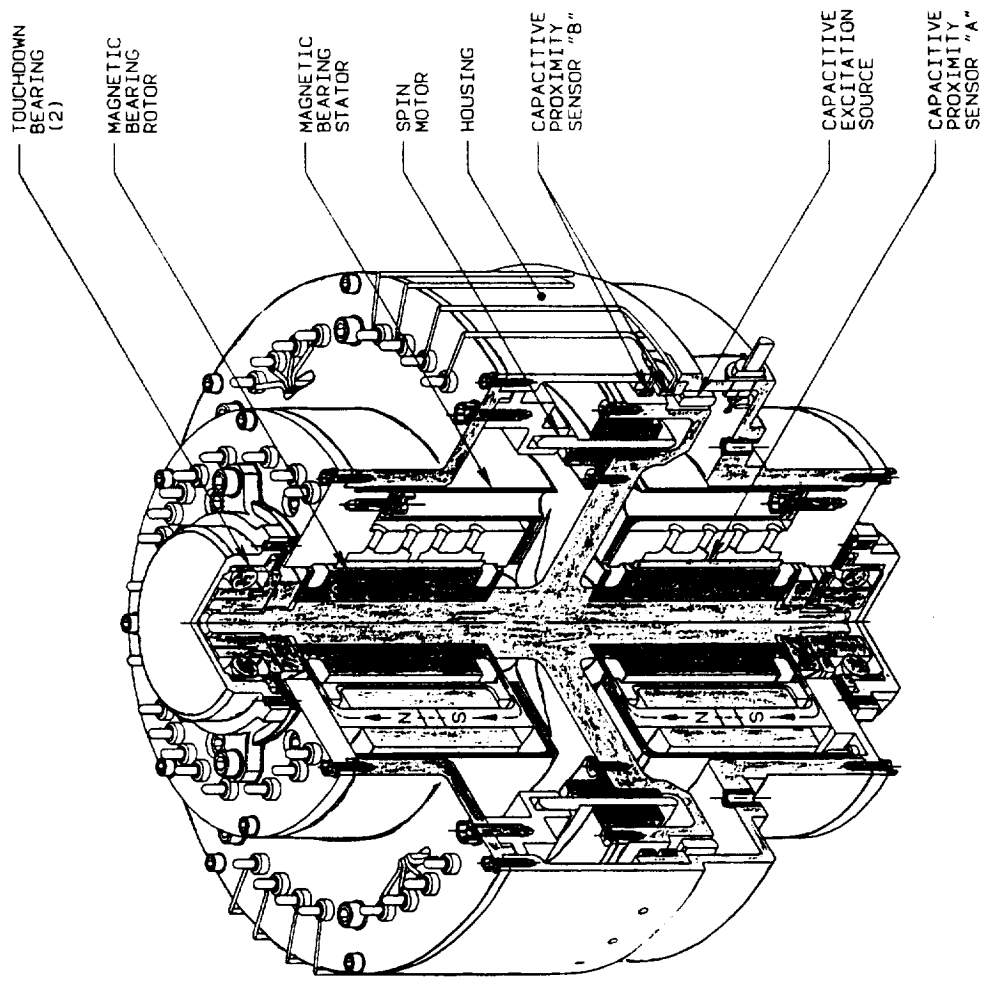


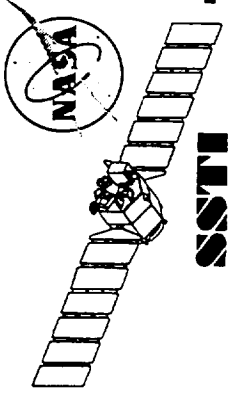
Existing Design

<u>Parameter</u>	<u>Source</u>	<u>Requirement</u>	<u>Capability</u>	<u>Comments</u>
Wheel Inertia	Derived	$3.5 \times 10^{-4} \text{ Kg} \cdot \text{m}^2$	Complies	Measured
Angular Momentum	AITP	$0.56 \text{ N} \cdot \text{m} \cdot \text{S}$	Complies	@15,000 RPM
Speed Range	"	+/- 15,000 RPM	Complies	To Be Tested
Torque Capability	"	$0.0175 \text{ N} \cdot \text{m}$	Complies	To Be Tested
Torque Sensitivity	Derived	$0.007 \text{ N} \cdot \text{m/A}$	Complies	To Be Tested
Size	AITP	11.4cm x 9.9cm D	Complies	Measured
<i>Weight</i>	"	<i>< 1.6 Kg</i>	<i>2.5 Kg</i>	<i>Added Housing</i>
Power	"	1.5 W ave.	Complies	To Be Tested
Lifetime	"	> 15 years	Complies	Goal >18 years
Inputs	"	Power On/Off, Torque	Complies	
Outputs	"	Speed, Direction	Complies	+Bearing Position



Magnetically Suspended Reaction Wheel Assembly Description - Cutaway View

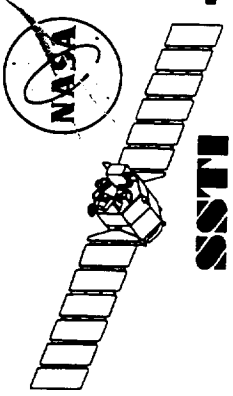




Magnetically Suspended Reaction Wheel Assembly Description - Reaction Wheel



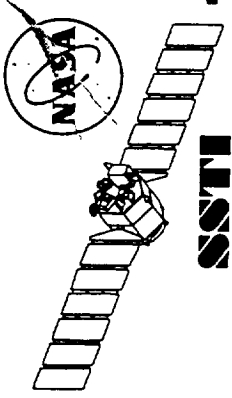
- **Spin Motor**
 - **Two Phase**
 - **Hall Sensors For Commutation**
- **Rotor**
 - **Titanium**
 - **Inertia $3.5 \times 10^{-4} \text{ Kg} \cdot \text{m}^2$**
 - **Angular Momentum $0.56 \text{ N} \cdot \text{m} \cdot \text{S}$ @ 15,000 RPM**
 - **Highest Stress Region Margin Of Safety 2.93 Above Ultimate**



Magnetically Suspended Reaction Wheel Assembly Description - Mag. Bearings



- One Pair Of Radially Active, Passive Axially Magnetic Bearings
Located On Each End Of Rotor Shaft
- Axial Stiffness 894 Kg/m
- Radial Unbalance Stiffness 13,227 Kg/m
- Rare Earth Samarium Cobalt Magnet For Axial Stiffness And Flux
Density Bias
- Electromagnet Control Coils For Radial Suspension And Position
Control Of Rotor



Magnetically Suspended Reaction Wheel Assembly Description - Position Sensor

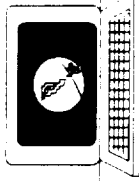


- Capacitive Radial Proximity Sensors
- 1 MHz, 10 Volt P-P Charge Transferred From Cylinder To Rotor Surface
- Transferred From Vanadium Permendur Rotor Flux Return Cylinder To Radial Proximity Sensors In Magnetic Bearings
- +X, -X, and +Y, -Y Sensor Rotated 45° To Control Coils To Eliminate Sensor/Magnetic Noise Interference

Autonomous Orbit Maintenance System (AOMS)

James R. Wertz

L. Jane Hansen



MICROCOSM, Inc.

Space Mission Engineering

8, 9 August 1996

**2601 Airport Drive
Suite 230
Torrance, CA 90505**

**Phone: (310) 539-944
FAX: (310) 539-7268
E-mail: jwertz@smad.com**



MICROCOSM, Inc.
Space Mission Engineering

LIST OF TOPICS

- Introduction to Microcosm
- Related Programs in Autonomy
- Autonomous Orbit Control
- AOMS System Summary
- Benefits of Autonomous Orbit Control



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Space Mission Engineering

INTRODUCTION TO MICROCOSM

- Aerospace analysis, engineering, and development business in Torrance, CA
- Principal products and services
 - Space mission engineering
 - Systems and mission engineering
 - Constellation design and analysis
 - Attitude determination and control system design and analysis
 - Spacecraft
 - Launch vehicles
 - Autonomous guidance, navigation, and control
 - Software engineering and development
 - Operational flight software
 - Analysis tools and simulation development
 - Low cost launch services
 - Sub-orbital rockets, light-lift, medium-lift, and heavy-lift programs
 - Will offer full launch services package -- low cost delivery to orbit

Microcosm has a 12 year history of finding ways to
Reduce the Cost of Access to Space



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RELATED MICROCOSM PROGRAMS

- Microcosm Autonomous Navigation System, MANS*
 - Flying as an experiment on-board TAOS (STEP-0)
 - Good data sets have allowed some tuning and processing on the ground to determine accuracy
 - TAOS Final Report, available in early 1997, will include “baseline” results of MANS performance

- Precision Autonomous Navigation and Orbit Control[†] Kit (PANOCK)
 - SBIR Phase I successfully completed
 - SBIR Phase II began in April 1996.
 - Goal is to create full control algorithms, packaged as flight ready software within 18 months of contract start.
 - Actively searching for test flight - candidates are EO-1 and MIGHTY SAT3.

* U.S. Patent No. 5,109,346

† U.S. Patent No. 5,528,502

**MICROCOSM, Inc.**

Space Mission Engineering

RELATED MICROCOSM PROGRAMS (CONT)

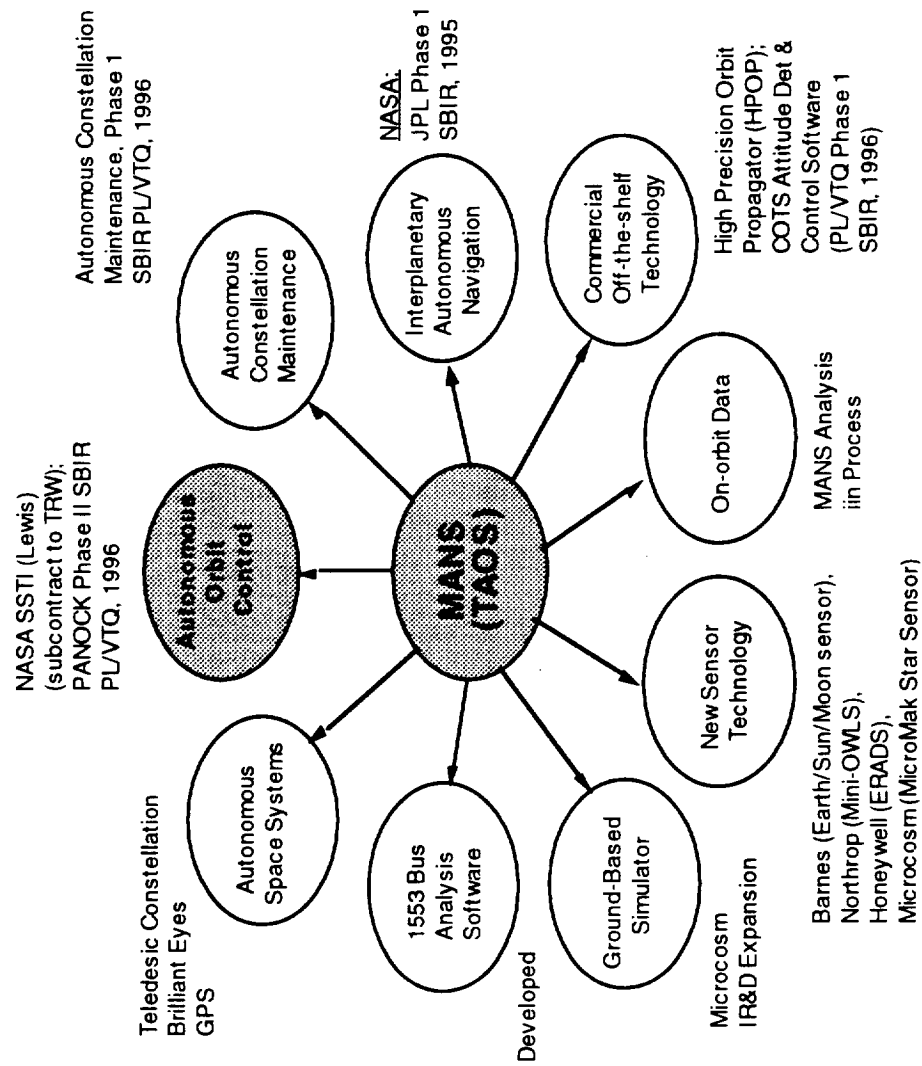
- **Autonomous Constellation Maintenance System Design**
 - SBIR Phase I contract awarded in April 1996 by Phillips Laboratory
 - Goal is to create a robust, redundant, low-cost, fully autonomous orbit maintenance system applicable to constellations at any altitude
 - Will allow operations-intensive surveillance, scientific, and commercial communications constellations to be economically viable to operate and maintain
- **Other major autonomous functions are currently available or in work**
 - Extensive on-board data verification done on TAOS as part of MANS
 - Earth and interplanetary efforts are in process
 - Interactive Spacecraft Response System can allow spacecraft to do much of what the ground segment has traditionally done

There is the potential for bringing about autonomous spacecraft guidance, navigation and control in the near-term with an appropriate test flight, with substantial long-term cost savings.



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Space Mission Engineering

CONSEQUENCES OF THE INITIAL MANS DEVELOPMENT



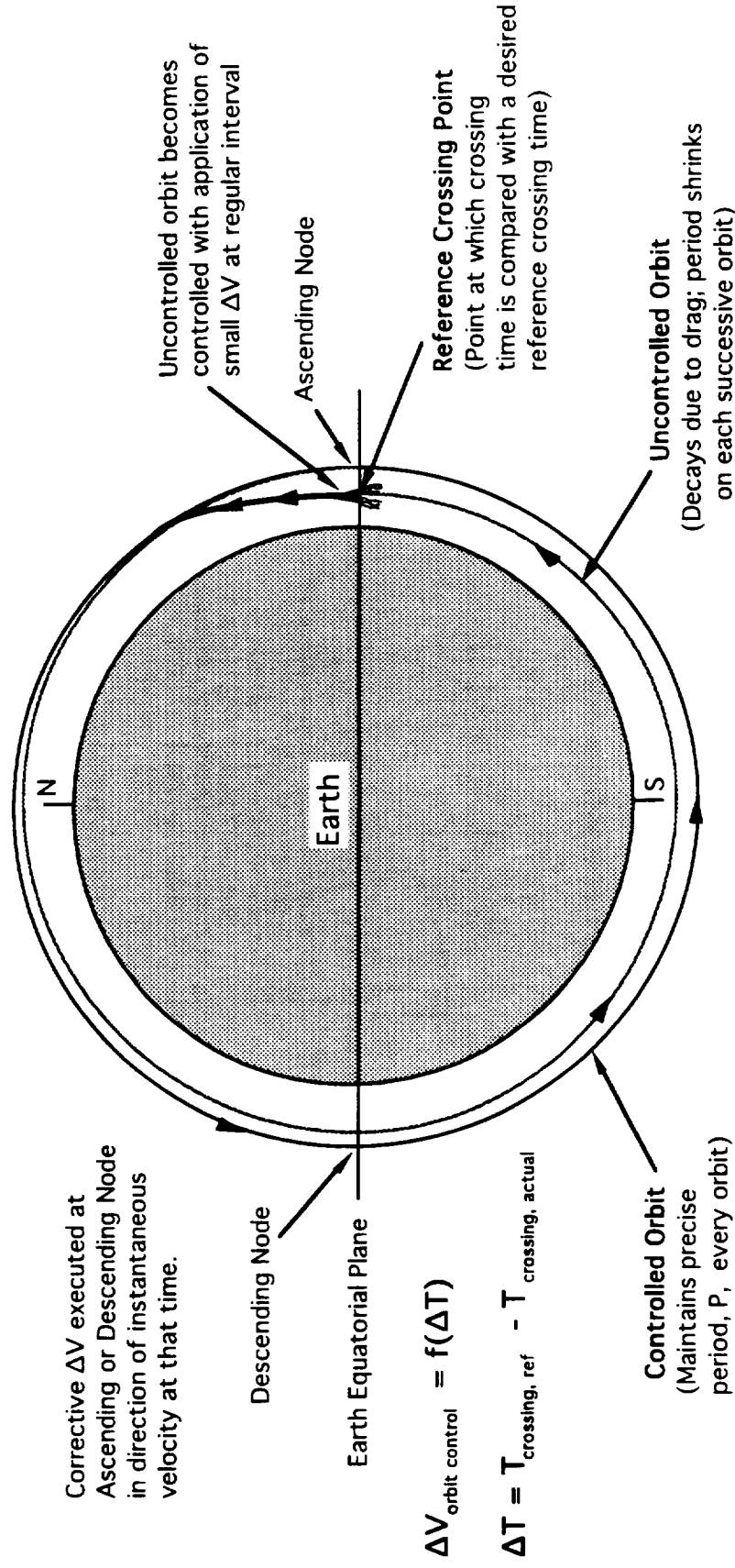


- Traditional Orbit Maintenance in LEO uses infrequent burns to maintain average orbit parameters
 - Variations in atmospheric density and drag (up to factor of 100) make it nearly impossible to accurately predict satellite motion and, therefore, to schedule precisely in advance
- Orbit Control uses frequent small burns to maintain the satellite in a precise, predetermined orbit
 - Position of each satellite is known at all times, even before launch
 - * Makes scheduling far easier
 - Does not use more propellant (spacecraft works smarter, not harder)
 - Does not require an on-board orbit propagator
 - Essentially like attitude control, only easier and more robust
 - * Unlike attitude, no major problems occur if orbit control is lost for a brief period

A *controlled orbit* is repeatable, easily predicted, and known in advance, whereas a satellite with traditional orbit maintenance is not.

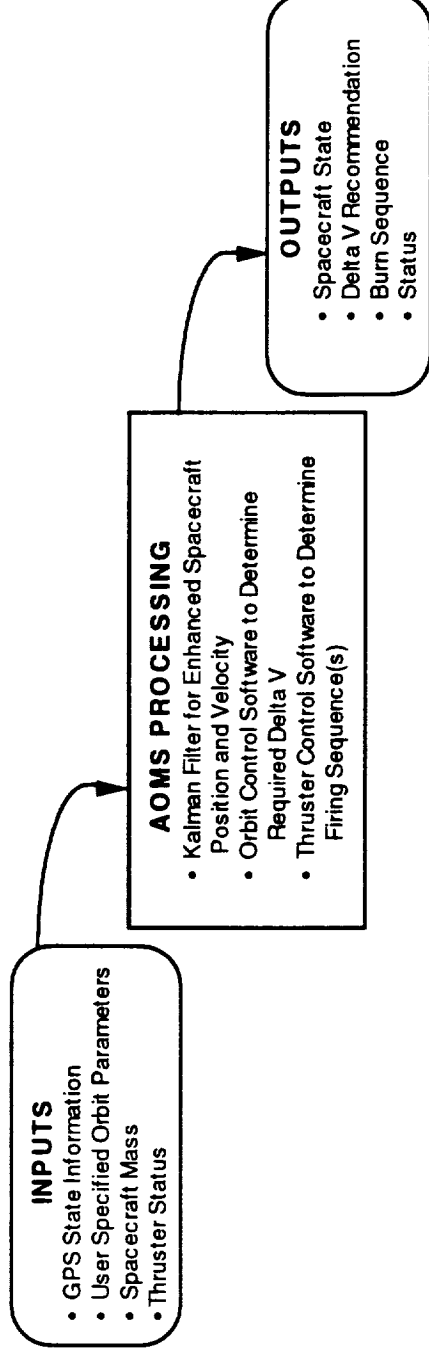


- Uncontrolled Orbit crosses Equatorial plane at successively shorter intervals ($P-\Delta P_i$), where ΔP_i increases on each successive orbit due to drag-induced orbit decay
- Controlled Orbit crosses the Equatorial Plane at a regular interval, P , on every pass
 - Corrective ΔV performed at Ascending or Descending Node
 - ΔV executed only if it is greater than a minimum threshold determined by thruster efficiency



AOMS SUMMARY DESCRIPTION

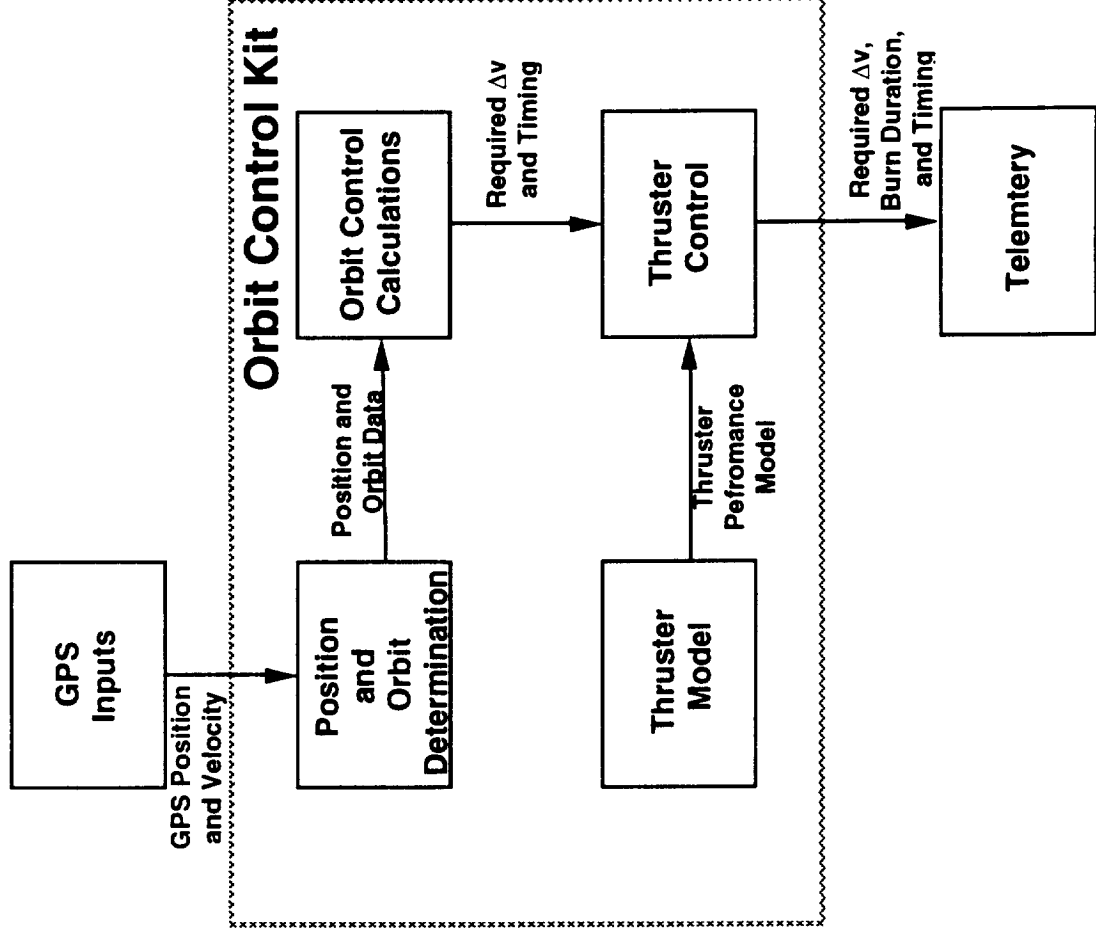
- AOMS provides Orbit Control for continuous maintenance as well as high fidelity position and velocity outputs.



- **Principal Features**
 - Control spacecraft orbit to fit a predetermined, exactly-known orbit schedule
 - ± 5 km in-track orbit control box provides open-loop timing accuracy to ≈ 700 ms for the lifetime of the satellite
 - Control spacecraft orbit to fit a predetermined, exactly-known orbit schedule
 - No ground orbit determination required
 - No ground station control required
 - Ground contact times and durations known well in advance



AOMS CORE COMPONENTS



- Low-thrust propulsion system providing controlled thrusting both in-track and cross-track, without requiring any more propellant than traditional orbit maintenance
- Thruster drivers and propulsion system control electronics
- Orbit sensing hardware (i.e., GPS receiver, Earth sensor, Sun sensor)
- MANS Autonomous Navigation software (Extended Kalman Filter)
- Microcosm Autonomous Orbit Control software



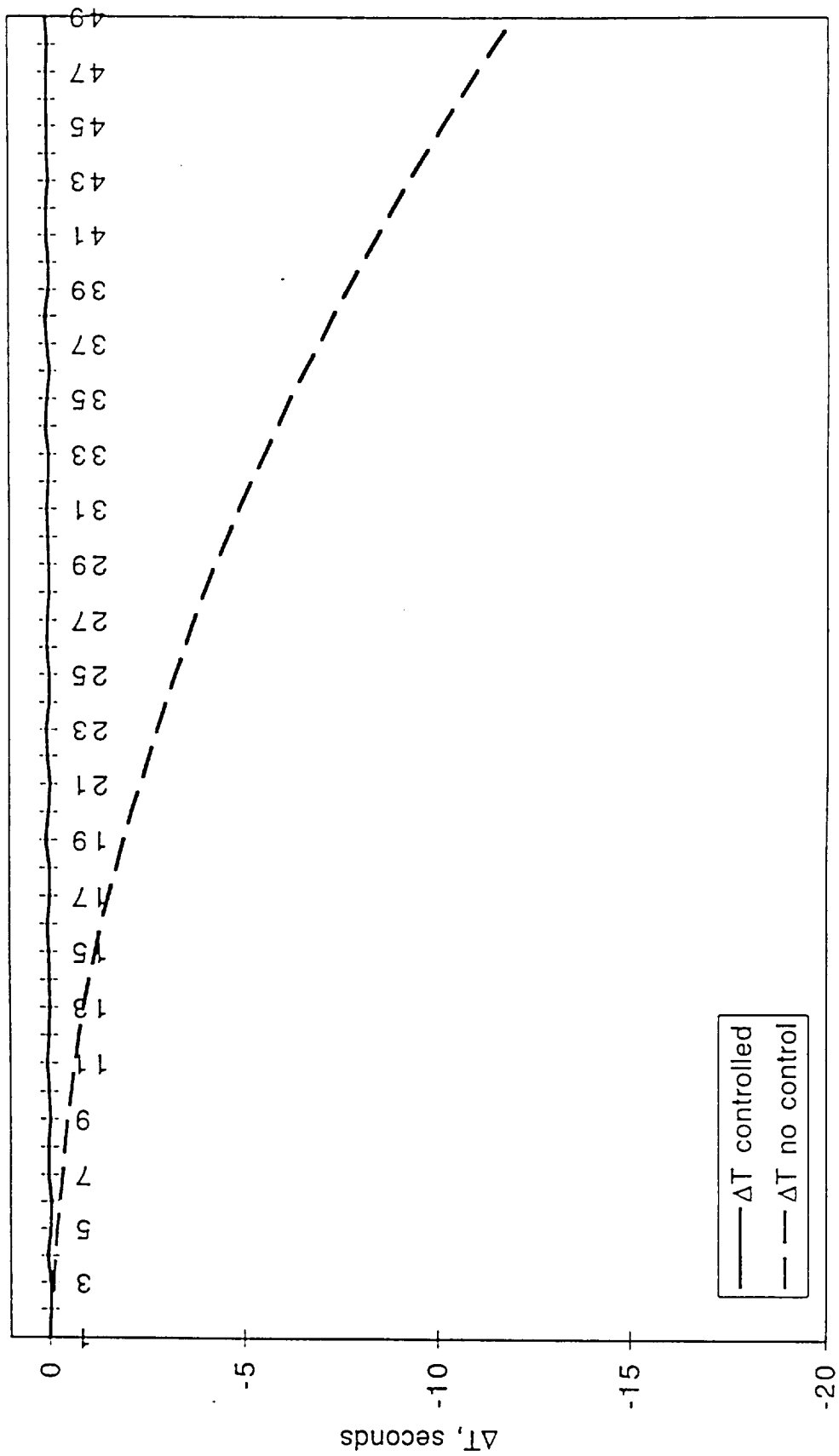
- **INPUT: Sixteen most recent samples of spacecraft state from GPS at one second intervals.**
 - Position, velocity and associated time tag
 - health/status word
- **INPUT: GPS week and UTC time offset**
- **INPUT: Desired Orbit Periods -- an array of four different orbit periods specified in seconds.**
 - Used to account for actual thruster firings which may differ from those recommended by AOMS.
- **OUTPUT: AOMS Status**
 - Indication of complete AOMS solution
 - Module status indicating completion of AOMS top level controller, Kalman Filter, Orbit Control, and Thruster Control software units
- **OUTPUT: Computed spacecraft state**
 - Position, velocity and associated time tag
 - Next Node Crossing State
- **OUTPUT: Suggested Orbit Control and Thruster Firings**



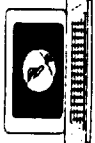
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ORBIT CONTROL SIMULATION RESULTS

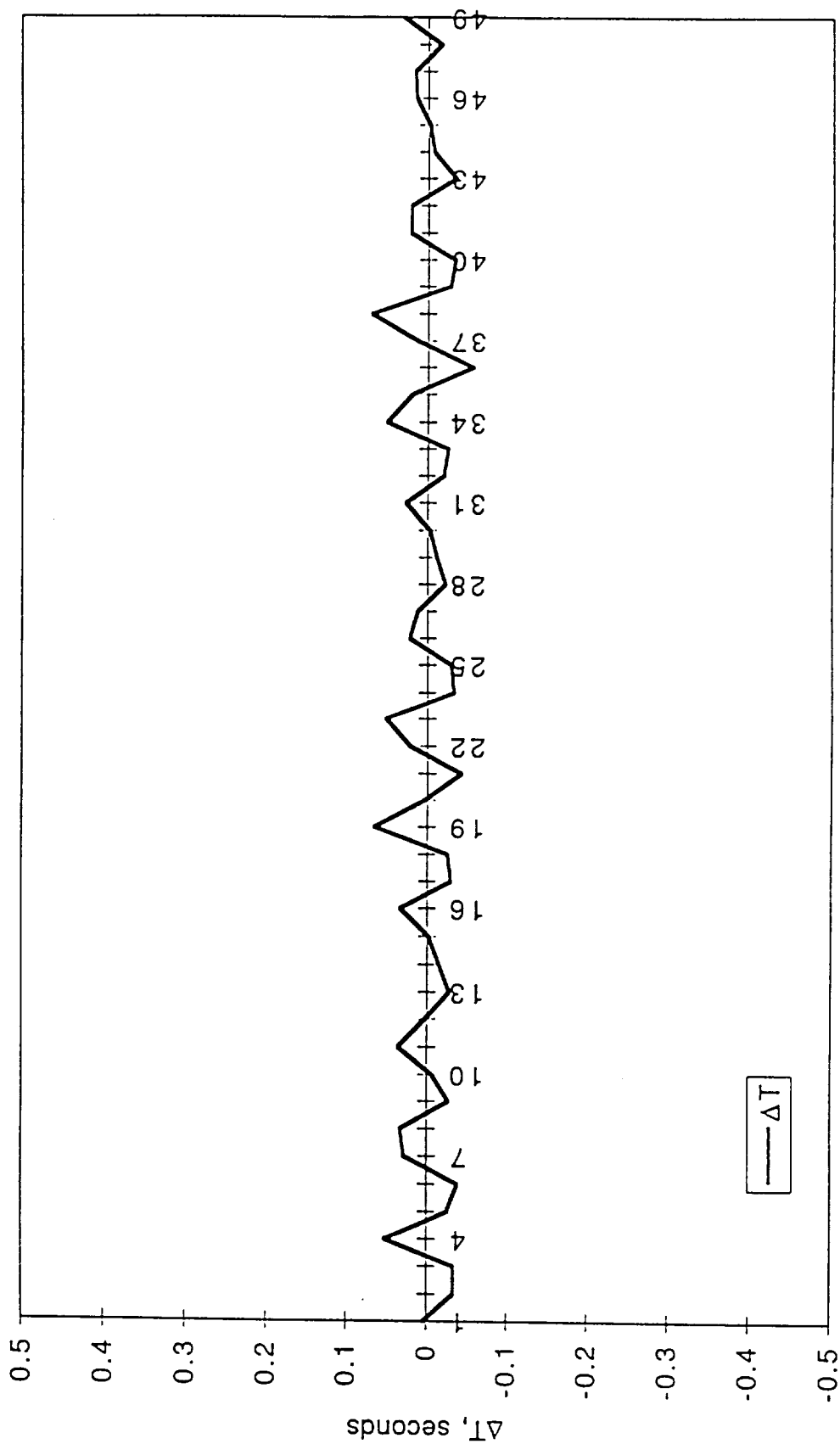


Orbit #



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ORBIT CONTROL SIMULATION RESULTS (2)

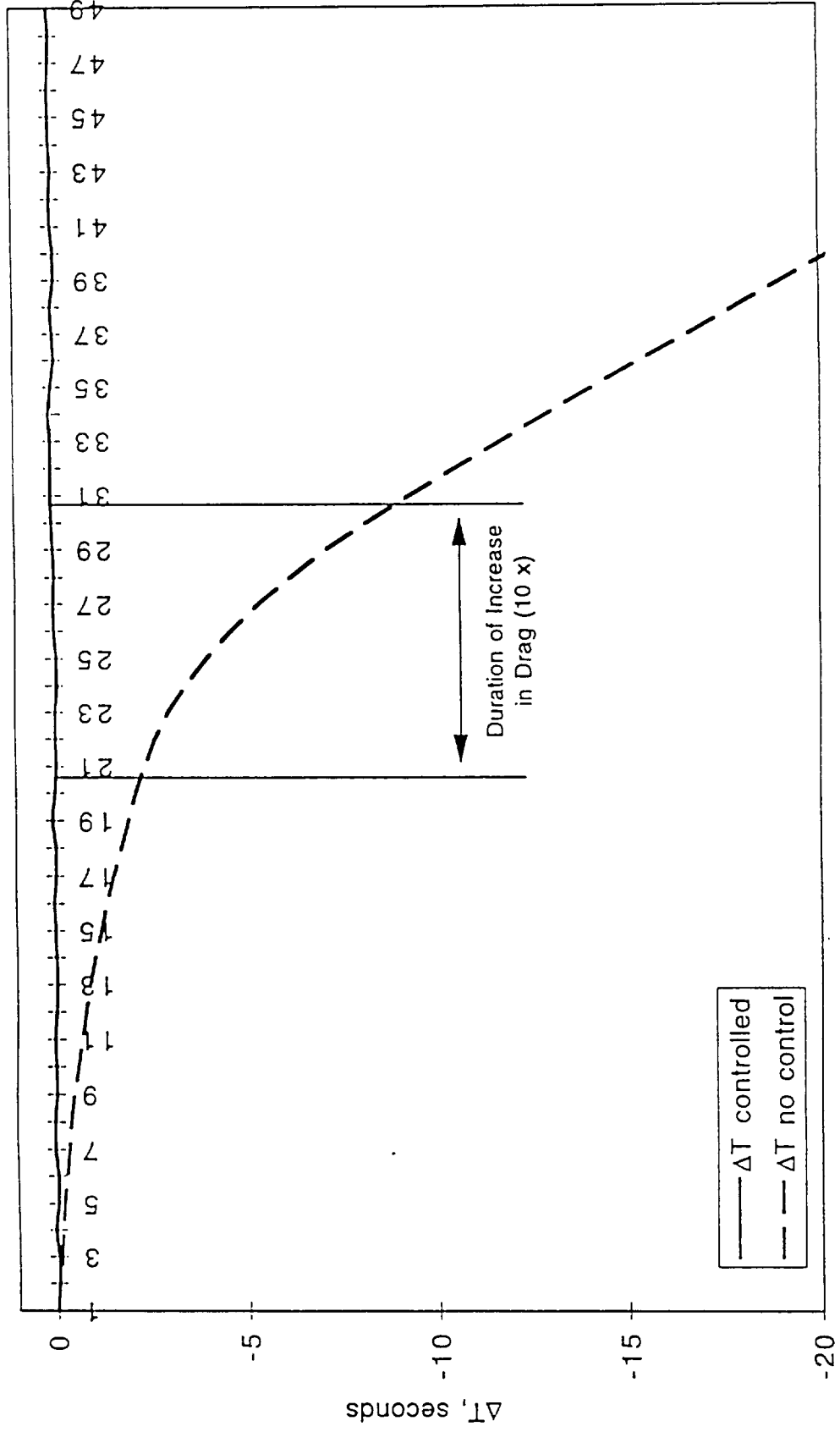


Orbit #



MICROCOSM, Inc. EFFECT OF 10-FOLD TEMPORARY DRAG INCREASE
STARTING AT ORBIT 20 AND LASTING FOR 10 ORBITS

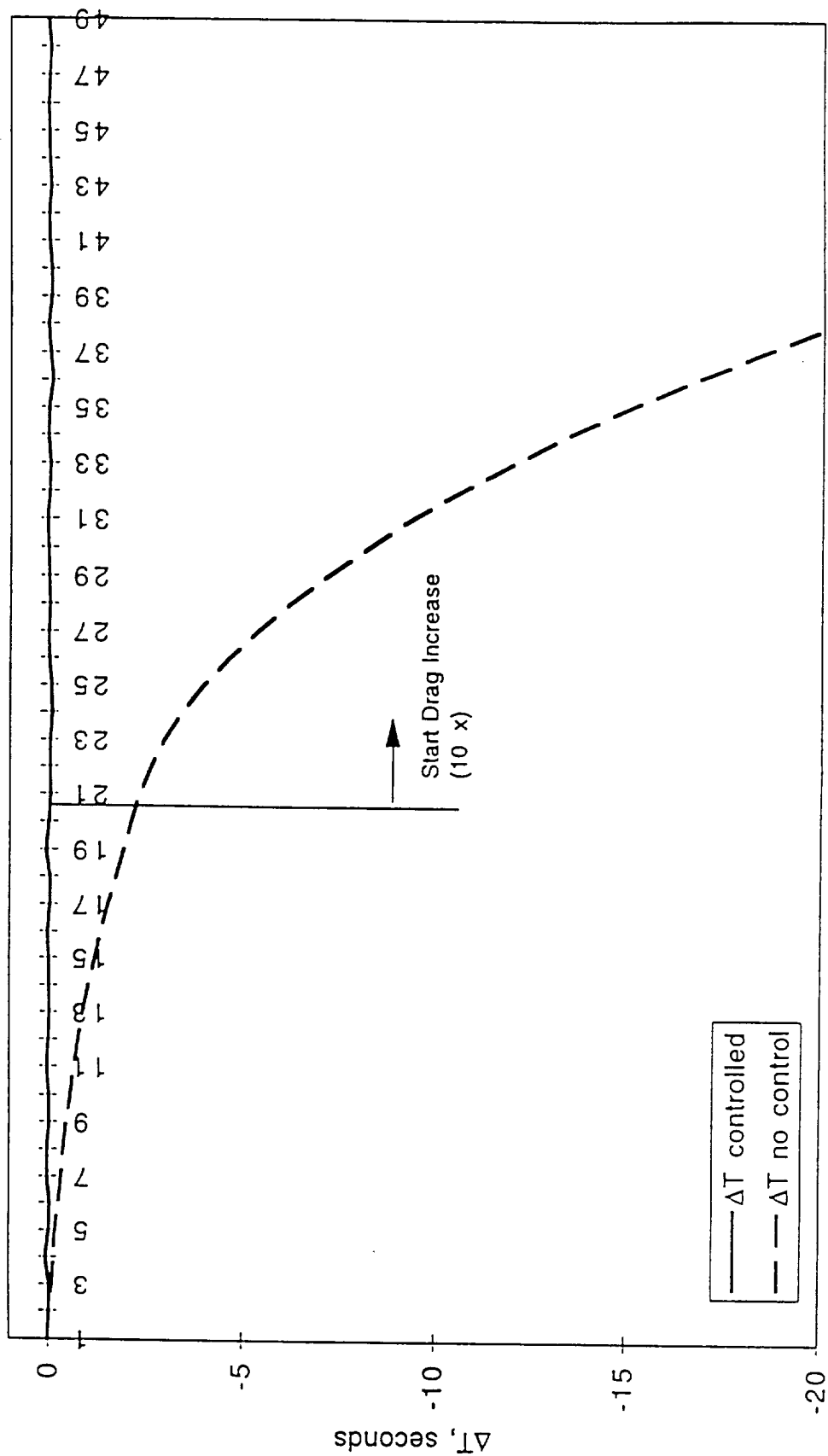
Space Mission Engineering





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Space Mission Engineering

EFFECT OF 10-FOLD STEP-FUNCTION DRAG INCREASE STARTING AT ORBIT 20





- Kalman Filter used for precision navigation is the one currently flying on TAOS mission (STEP-0)
 - Modified to filter GPS solutions
 - Back-up solution uses standard Sun and Earth sensors
- Prototype orbit control algorithms will be flown on SSTI mission (Lewis spacecraft)
 - Only a “proposed ΔV sequence” will be computed
 - Will not be allowed to fire the thrusters
- PANOCK Phase II SBIR proposes to implement the flight demonstration via “phased autonomy”
 - Step 1: Compute firing on-board, require ground authorization to execute
 - Step 2: Compute firing on-board, execute after delay to allow ground override
 - Step 3: Compute and execute on-board, send to ground for verification
 - Step 4: Fully autonomous, check only as desired



- Reduced operations cost due to elimination of need for stationkeeping maneuver planning, command uploading, execution, and verification
 - Eliminates need to continuously update schedule of future activities
- Reduces computational load both on the ground and on-orbit (comparable to automatic attitude control, only much lower frequency)
 - Do not need precision orbit propagation on the ground or on-orbit
 - Reduces hardware cost and complexity
- Tighter control -- fully automatic stationkeeping with smaller control boxes
 - Allows the packing of additional satellites in the same GEO slot
 - Allows tighter constellation control
- No added propellant cost -- possible slight propellant savings
- Reduced Risk
 - Reduced risk of incorrect commanding, communications errors, and outages
 - Failed or improper burn not a problem -- results in slow drift from the nominal position that can be corrected on subsequent burns, can be made inherently fail safe
- Less interference with payload operations because of very low thrust burns



- **Advantages**
 - Uses equipment already on-board most spacecraft
 - Major operations cost savings – particularly in constellations
 - May reduce hardware weight and cost by using smaller thrusters
 - Simple algorithms and low frequency execution imply negligible impact on computer resource requirements
 - Inherently fail-safe, unlike attitude control
 - Allows treating orbit and attitude as a systems problem – design an orbit/attitude control system to minimize the cost of both
- **Disadvantages**
 - Places additional requirements on on-board hardware
 - Requires operational plan for gradual transition to autonomy
 - Requires treating orbit and attitude as a systems problem – design an orbit/attitude control system to minimize the cost of both

**Autonomous Orbit Control reduces cost and risk and is technically straightforward,
but requires a willingness to change how we fly spacecraft.**

SSTI LEWIS WORKSHOP '96

Data Compression Experiment

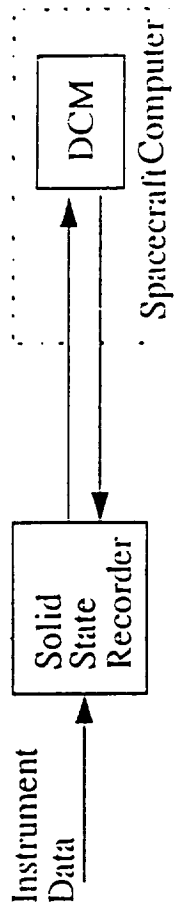
PI: Warner H. Miller
(301)286-8183 whmiller@pop700.gsfc.nasa.gov

Co-I: Pen-Shu Yeh
(301)286-4477 psych@psy.gsfc.nasa.gov

Data Compression Experiment on Lewis

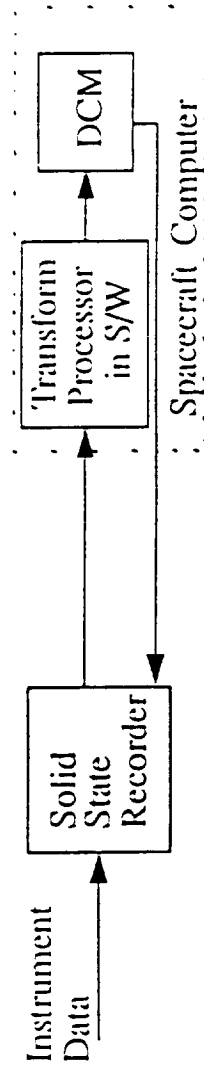
- Lossless Data Compression

Implemented in hardware Data Compression Module (DCM) using Universal Source Encoder for Space (USES) chip. DCM housed in spacecraft computer, will be applied to HSI and LEISA data.



- High Performance Data Compression

Implemented partly in software and partly in hardware utilizing DCM board. Will be applied to HSI and LEISA data.



DATA COMPRESSION TECHNOLOGY

BENEFITS ON NASA MISSION

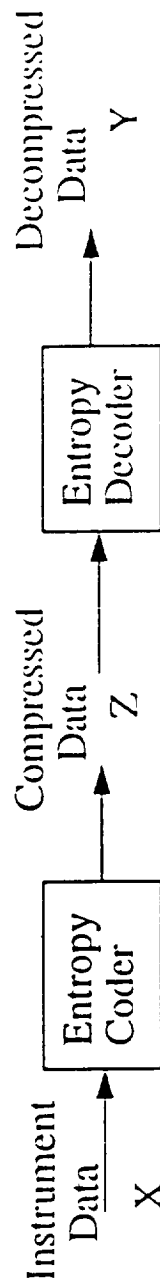
USAGE	IMPACT	COST SAVING
Onboard Solid State Recorder Capacity Requirement	Reduce to 1/2 using lossless compression Reduce to 1/10 using lossy compression (1) & (2)	> Millions for EOS
Bandwidth	Reduce to 1/2 using lossless compression Reduce to 1/10 using lossy compression	
Antenna	Reduce EIRP by 3db (1)	> Millions
Station Contact Time	Reduce to 1/2 using lossless compression Reduce to 1/10 using lossy compression	
System Engineering	Allow better utilization of resources; direct broadcast capability for NOAA- 2000, Landsat, etc.; eliminate need to con- struct/maintain additional ground stations.	> xx Millions per mission
Data Archives Capacity Requirement	Reduce to 1/2 using lossless compression. Allow browsing capability using lossy compression. (1) & (2)	> Millions per mission
Data Dissemination (Transmission Time)	Allow faster data retrieving and routing between archival centers and users	

(1) Size/Weight (2) Power

DATA COMPRESSION TECHNOLOGY

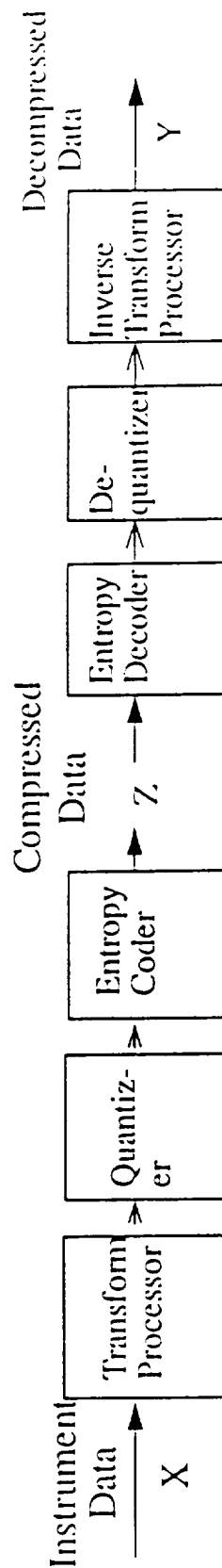
WHAT IS IT

- Lossless Data Compression: Also known as entropy coding, it reduces data size by removing redundancy. The decompressed data has NO DISTORTION. Data reduction is limited by the total information contained within the data. The developed technique is based on the Rice algorithm.



$$Y = X$$

- High Performance Data Compression: Also known as lossy data compression, it reduces data size by a much larger factor. The decompressed data will have DISTORTION. The developed technique combines Modulated Lapped Transform(MLT) with Discrete Cosine Transform(DCT).



$$Y \sim X$$

DATA COMPRESSION TECHNOLOGY

ISSUES ADDRESSED

- Variable-length compressed bit string requires packet data structure for transport.
- Buffer required for smoothing data rate.
- Clean channel required for compressed data stream for error containment.
- Instrument interface:

Detector to detector variation requires radiometric correction.

Multi-spectral mode requires registered IFOV sampling of data.

DATA COMPRESSION TECHNOLOGY

CURRENT STATUS

Lossless Compression Technology

- Both hardware flight qualified silicon (VLSI) encoder chip and software in C are developed and fully tested.
- Decompression VLSI chip is currently in design phase, with delivery planned in Dec., '96.
- CCSDS International Recommendation for lossless data compression Red Book has been reviewed favorably, Blue Book expected end of '96.
- The algorithm is implemented in software in three flight instruments: gamma-ray spectrometer on Mars Observer (lost in orbit), SWAS on the Small Explorer (launch Dec. '96) and a spectrometer on the Mars-96 mission.
- Software is currently under integration by Space Science Data Center at Goddard into Common Data Format (CDF) for distribution of science data.
- The VLSI hardware encoder is integrated on two flight missions: the "Lewis" mission of the Small Satellite Technology Initiative (SSTI, launch Nov. '96) and the Solar Extreme UV Rocket Telescope Spectrograph (SERTS, launch summer '96) built by Goddard Space Flight Center.
- The hardware encoder is under consideration by several defense agencies for missile applications and by aerospace companies for commercial satellites.
- Hardware encoder is baselined for EOS-PM, AM2, GOES-2000, NMP/EO-1, GATES, VENUS-2000.
- Software encoder is baselined for MAP/MIDEX mission.

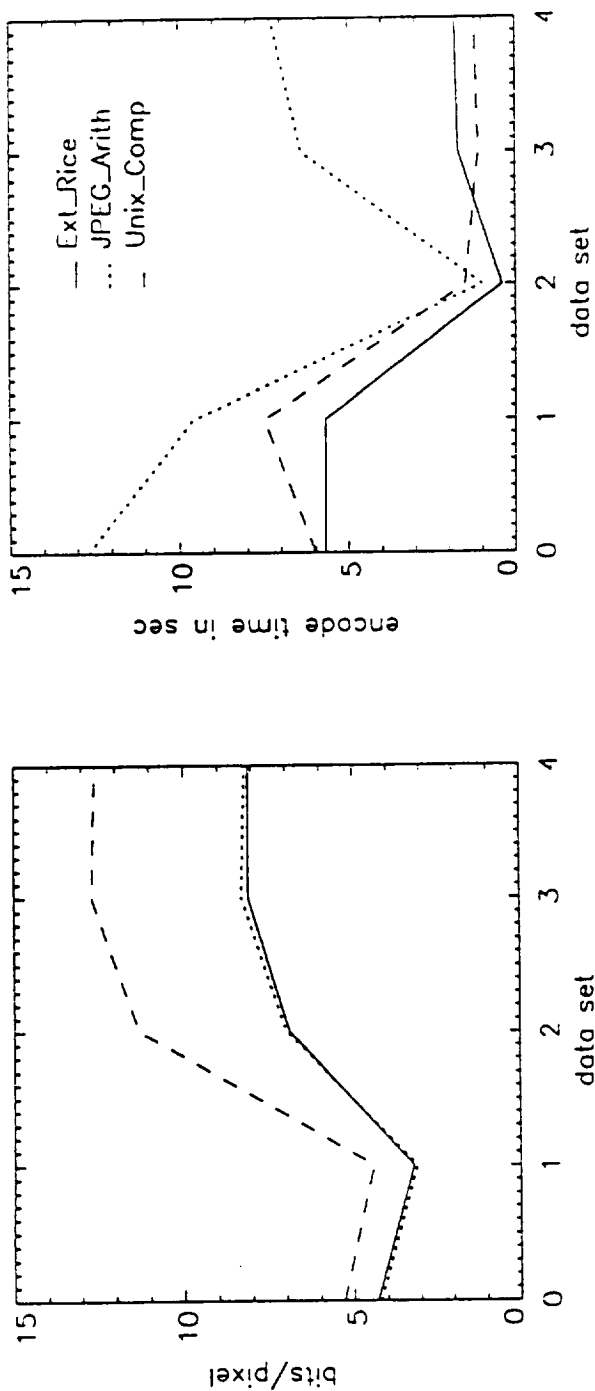
High Performance Compression Technology

- Silicon circuit design of the major processor (Enhanced DCT) block began early 96, preliminary specs written.
- Hybrid system composed of partial software and partial hardware was integrated in SSTI/LEWIS to process hyper-spectral imager data, launch Nov. 96.
- Baseline for NMP/EO-1 and VENUS-2000

Contact

- For algorithm, applications: Warner Miller (301)286-8183, whmiller@pop700.gsfc.nasa.gov or Pen-Shu Yeh (301)286-4477, psyeh@psy.gsfc.nasa.gov
- For ordering chips and commercialization of entropy coder software: Dr. Gary Maki (505) 277-9700, maki@mrc.unm.edu
- For general information: check web site at <http://www.mrc.unm.edu>

LOSSLESS DATA COMPRESSION



data set: 0: Landsat 1: Solar 2: AOS 3: MRI 4: Seismic

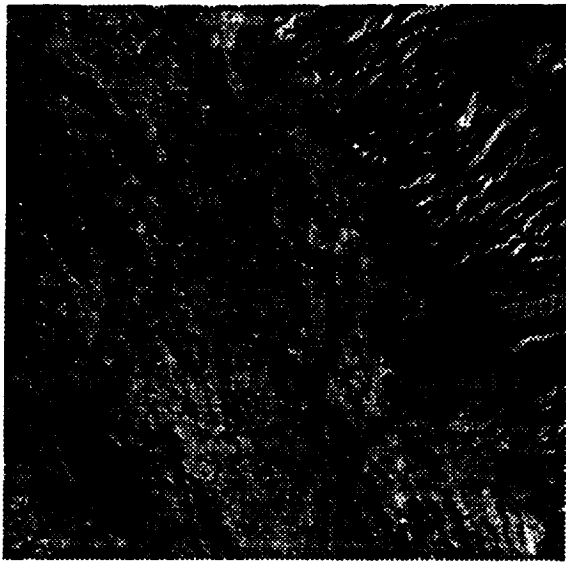


Figure 4. Landsat-4 Data

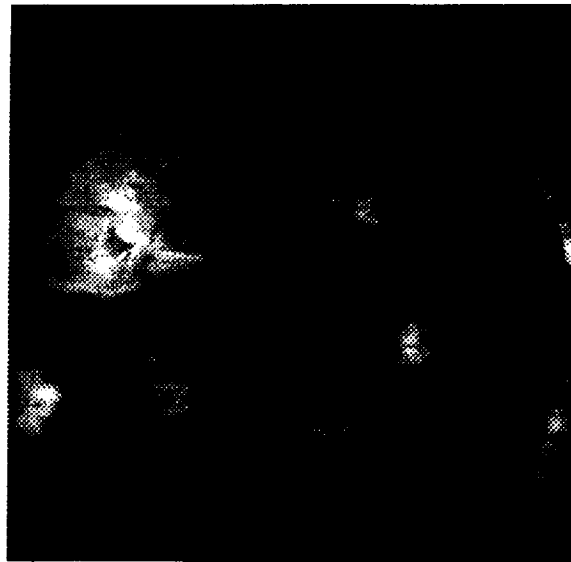


Figure 5. Solar X-ray Data

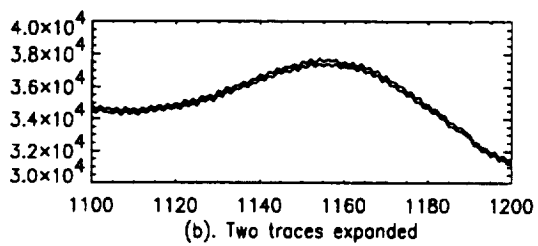
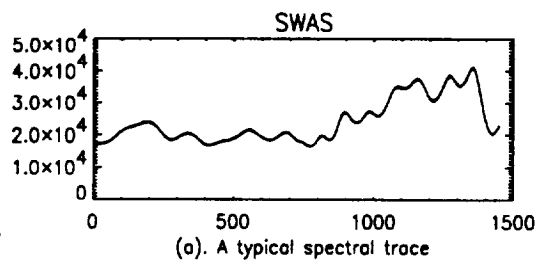


Figure 6. AOS Data

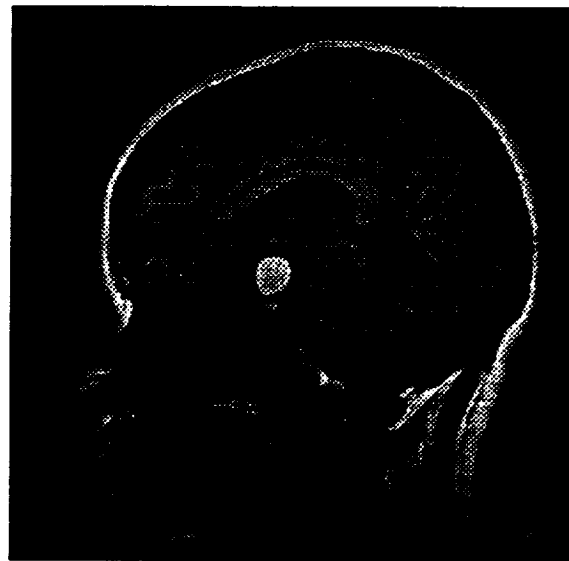


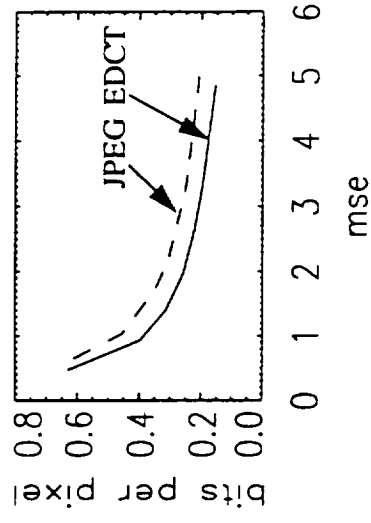
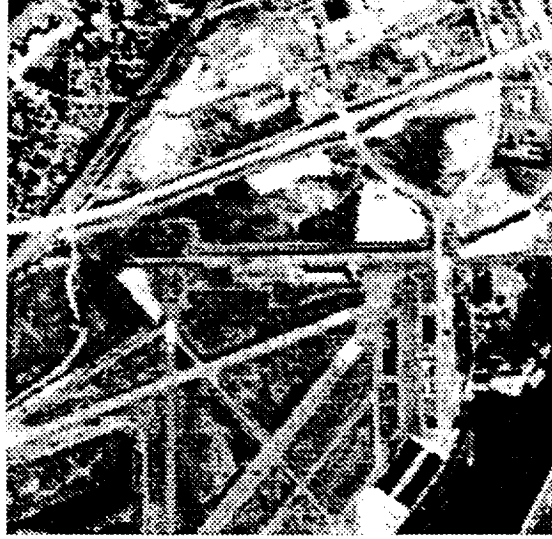
Figure 7. MRI Data



Figure 8. Seismic Trace

Performance

Airport Image: 512x512, 8bit



R & D Efforts currently under development at GSFC

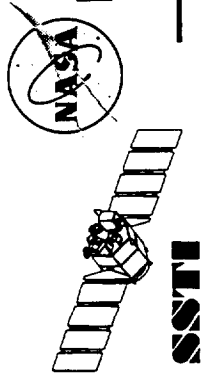
1. Channel Coding Technology

- Turbo Code: rate $1/2$ with 9 db coding gain, in collaboration with Univ. of Notre Dame (Prof. Dan Costello)
- Trellis Coded Modulation: 2.5 bits/hertz, in collaboration with New Mexico State University (Prof. Steve Horan)
- High Rate Viterbi Decoder: 1 G bps, rate $3/4$ with 4.5 db coding gain, in collaboration with U. of Hawaii (Prof. Shu Lin)

2. Data Compression

- Combining source and channel coding, in collaboration with U. of Nebraska (K. Sayood)
- Continue exploring next generation compression techniques

3. Dual Use ASIC Technology (flight chip produced at commercial foundry): in collaboration with Univ. of New Mexico (Prof. Gary Maki)



August 9 – Session 5
Independent Technology Demonstrations–
Continued



8:00-11:45 – Park Patio Cafe – Chair: Dick Woods

	<u>Speaker</u>	<u>Time</u>
• Metal Matrix Heat Strap	Gordon Casto	8:00-8:30
• Radiation Counter	Judy Shinn	8:30-9:00
• Clouds and Features Editing	Harry Benz	9:00-9:30
• Advanced RISC RH-32 Packaging Experiment	Rudy Almeida	9:30-10:00
• Photovoltaic Regulator Kit Expt.	Tony Baez	10:00-10:30
• MIMO Attitude Control	Peiman Maghami	10:30-11:00
• Goddard Experiment Module	Phil Luers	11:00-11:30



Metal Matrix Composite Heat Strap (MMCHS) & AeroHeating Sensor

Gordon V. Casto
Mechanical Engineering Branch
NASA/Goddard Space Flight Center



Metal Matrix Composite Heat Strap Technology Demonstration

Technology Developers

Goddard Space Flight Center, Greenbelt, MD

Naval Surface Warfare Center, White Oak, MD

DWA Inc., Chatsworth, CA

Point Of Contact

Gordon Casto, Goddard Space Flight Center

Code 722

Greenbelt, MD 20771

gordon.casto@gsfc.nasa.gov

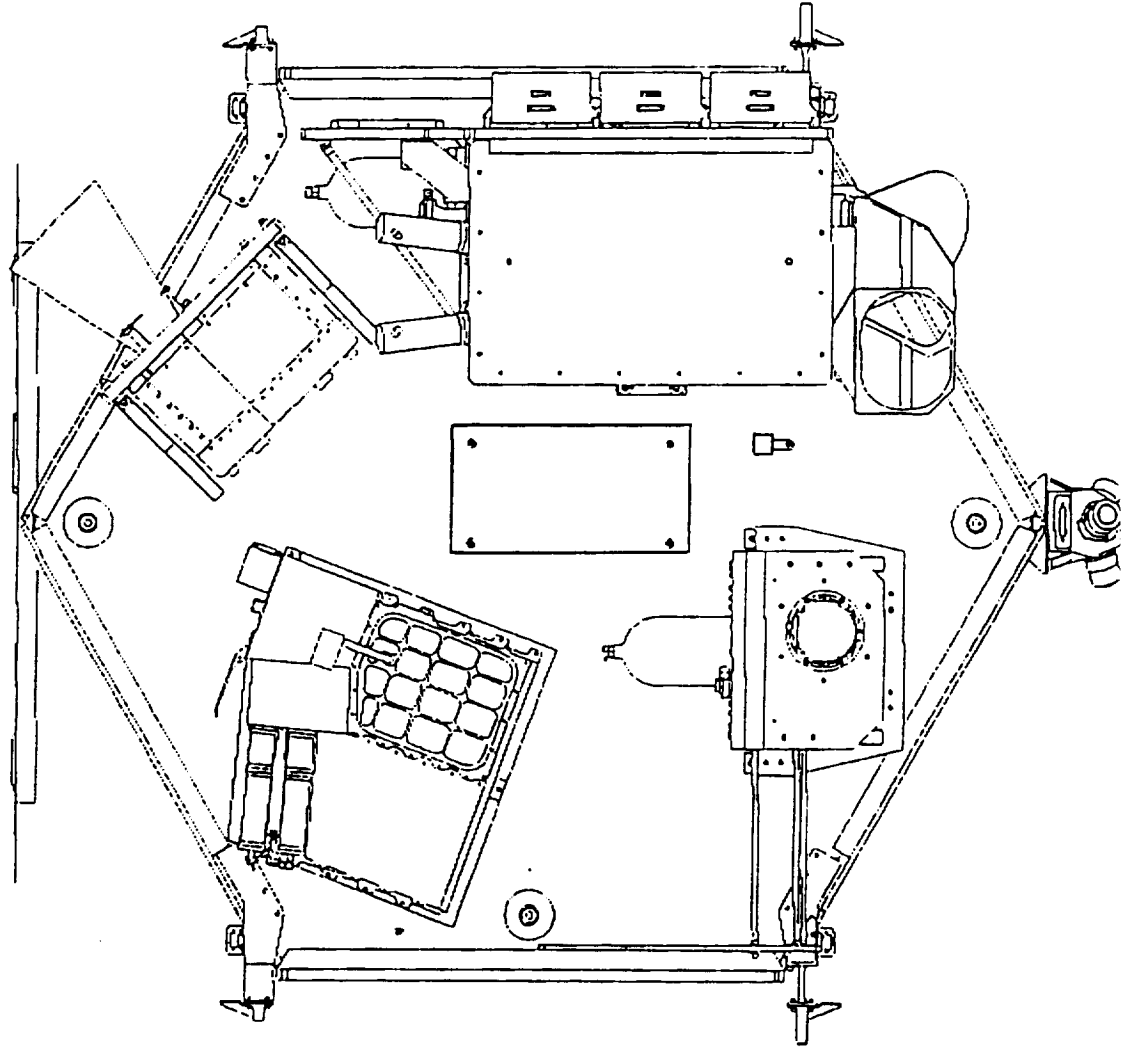


Agenda

- ❖ Introduction (MMCHS)
- ❖ Preliminary Data
- ❖ Benefits and Uses for MMCHS
- ❖ Introduction (AeroHeating sensor)
- ❖ Benefits AeroHeating sensor
- ❖ Conclusions



Metal Matrix Composite Heat Strap Technology Demonstration





Introduction

- ❖ The technology demonstration consists of the "K1100/Aluminum Thermal Strap" coupling an electrical resistance heat source to a space facing radiator.
- ❖ The experiment will measure the strap performance over a temperature range of -40 C to 20 C. This data set will be correlated to ground test data range of -80 C to 50 C.
- ❖ Thermal Strap is utilizing high thermal conductivity graphite reinforced aluminum foils (0.0045" DWG process)
- ❖ Strap developed in stages from Pure Aluminum (1100 alloy) to P120/Aluminum to K1100/Aluminum (P120 and K1100 are graphite fibers produced by Amoco Performance Products Inc.)
- ❖ The strap construction consists of 20 stacked layers of the MMC material cut to 12"x1.5" and adhesively bonded on the ends. The bonded area on the strap end is 1.5"x1.5".



Preliminary Data

	MMCHS (K1100/Al)	Copper	Aluminum
Specific Thermal Conductivity (k/ρ)	very high 108	medium 31	high 57
Flexibility/Watt	Medium	Medium	Medium-High
System Costs	Low	Medium	High
Length w/o Splice	18"	None	None



MMCHS Uses

Uses

- ❖ Simplify Complex Heat Pipe Designs (1g Testing)
- ❖ Individual component cooling on electronic cards
- ❖ Cryo-Cooler High End Heat Rejection (save 1.5Kg on a 5Kg system)
- ❖ Thermal Hinges
- ❖ High Efficiency Radiator w/ or w/o Heat Pipes.
- ❖ Other developments at GSFC
 - P120/CyE/Aluminum Circuit Card Heat Sinks. Parts Material Process List (PMPL) being developed.
 - Low thermal expansion heat pipes for embedding in graphite facesheet honeycomb



AeroHeating Sensor

- ❖ After faring separation aerodynamic effects are negligible on the launch vehicle and payload, however,...
- ❖ Aeroheating can subject exposed lightweight items to extreme heating rates.
- ❖ Factors affecting aeroheating:
 - Altitude, Velocity, Sun activity, Exposed component mass, Material.
- ❖ The bulk of the spacecraft is not affected.
- ❖ Heating rate is usually calculated by the launch vehicle vendor, based on intended trajectory. This calculation treats the boundary layer and free molecular heating rates separately. This method usually conservatively overestimates the heating rate.
- ❖ There are analytical models, both simple and extremely academic, that try to address the subtle interaction between the two regions. These models have however have not been verified with flight data.



AeroHeating Sensor

- ❖ Satellites have been lost to "Aeroheating"
- ❖ Current methods conservatively overestimate heating rates
- ❖ If current analysis indicates overheating a more realistic heating rate may indicate acceptable margin.
- ❖ Because of the lack of data, more dramatic measures are employed:
 - Faring separation delayed (mass to orbit reduced)
 - Configuration changes
 - Design changes
- ❖ Aeroheating is rarely a concern, but when it becomes a concern, it is dealt with late in the program schedule.



AeroHeating Sensor

- ❖ A low mass sensor is mounted in the velocity direction on the spacecraft.
- ❖ The sensor is approximately 3/4" square by .010" thick aluminum. A thermal sensor (AD590m) is bonded to the back side of the aluminum.
- ❖ The sensor is supported by a machined piece of Delrin. The Delrin can be bonded to various support pieces to accommodate different positions on various spacecraft.
- ❖ The sensor currently will be flown on the FAST spacecraft (PegasusXL launch) and the Lewis spacecraft (LLV1 launch), both from the WTR.

RADIATION COUNTER

By

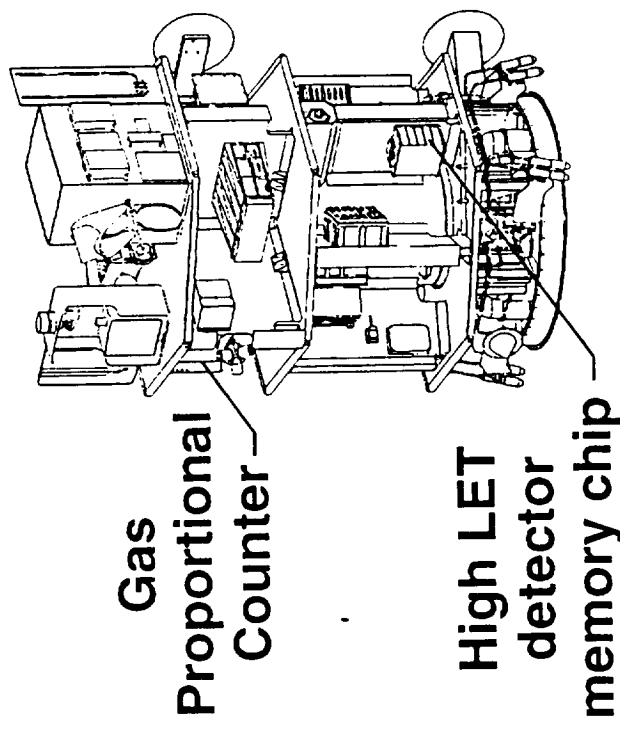
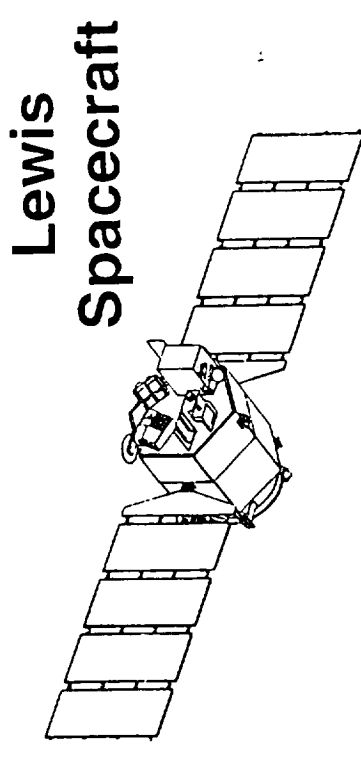
**Judy Shinn
NASA Langley Research Center**

**SSTI Lewis Workshop
August 8 and 9, 1996**

NASA/TRW SSTI LEO ENVIRONMENT PROBE

Nov. 1996, 523 km, 97.45° inclination

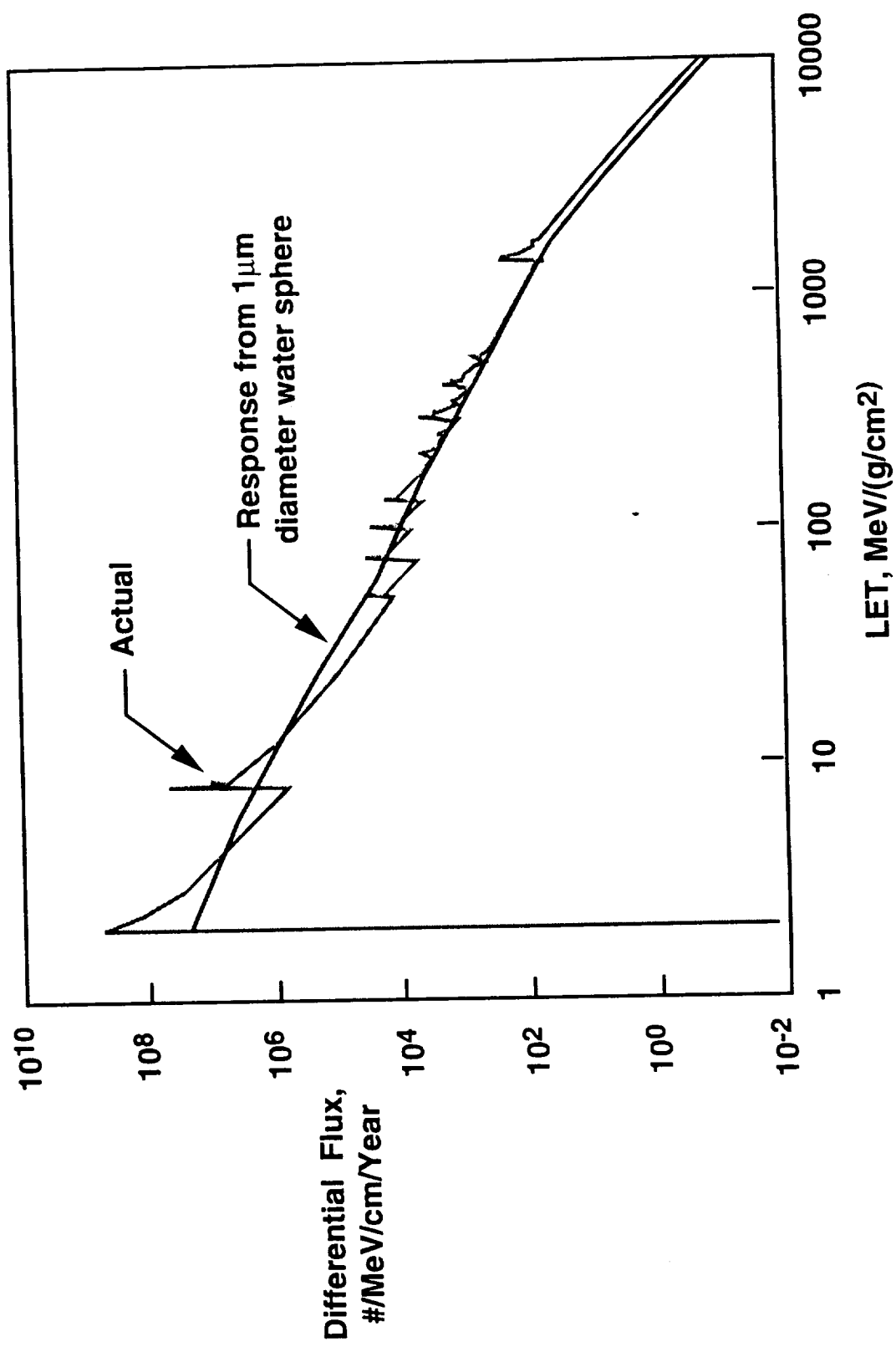
- Measurement of LET spectral distributions
- Secular variation in trapped radiation components
- Solar modulation of Galactic Cosmic Ray exposures
- Effects of magnetic storms
- Possible solar cosmic ray measurements
- Validation of shield design methods



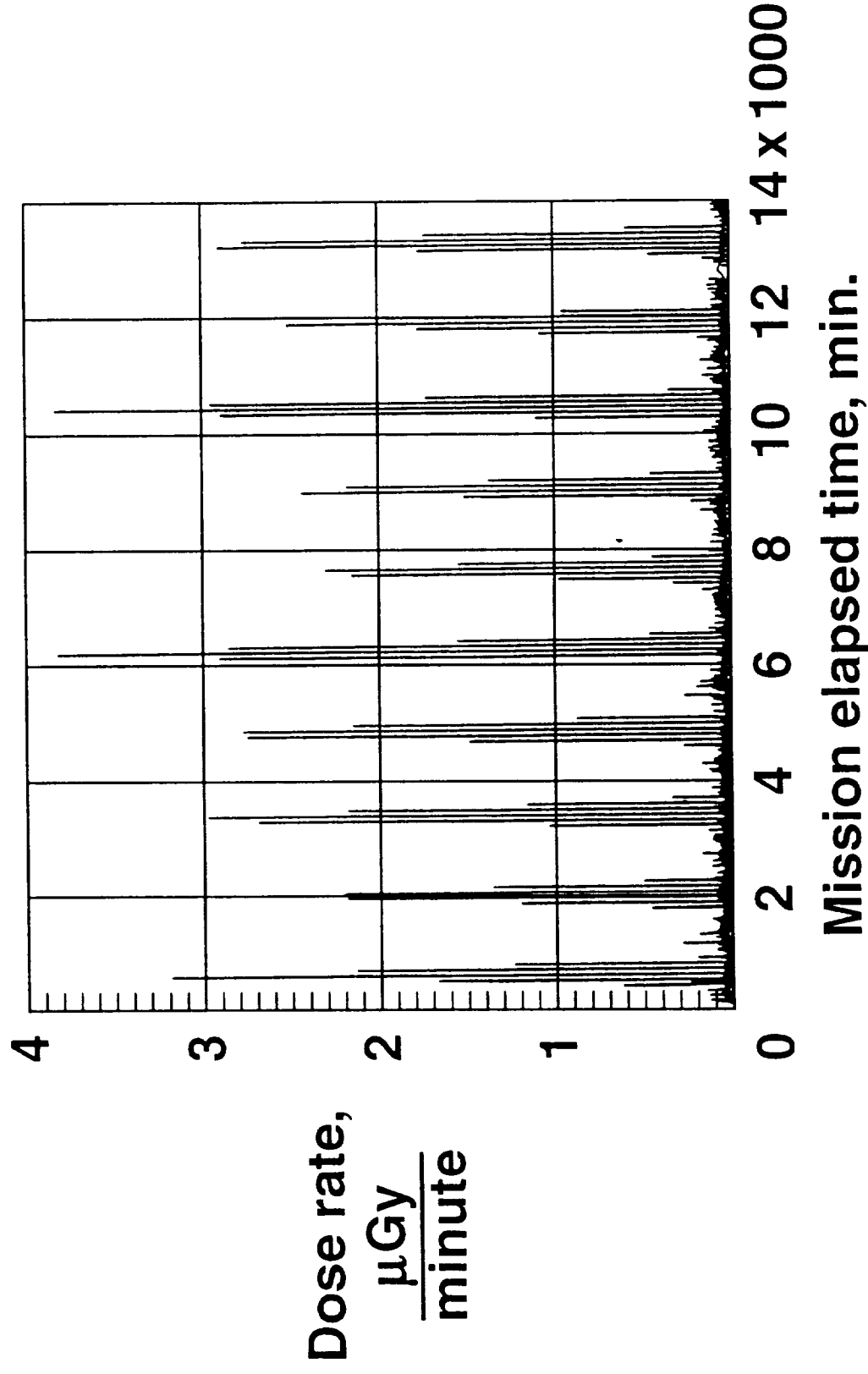
GPC DESCRIPTIONS

- Measure LET spectrum of radiation in LEO from 0.3 to 1250 keV/ μm
- Low pressure gas in detector; operate in linear portion of gas gain vs. voltage regime
- Amplified voltage output is pulse height analyzed in a 256-channel ADC
- Resolution: 0.1 keV/ μm below 20 keV/ μm
5.0 keV/ μm above 20 keV/ μm
- Full spectrum recorded one or two minutes on RAM
- Less than 2.5% gain shift within 50-70 degrees C

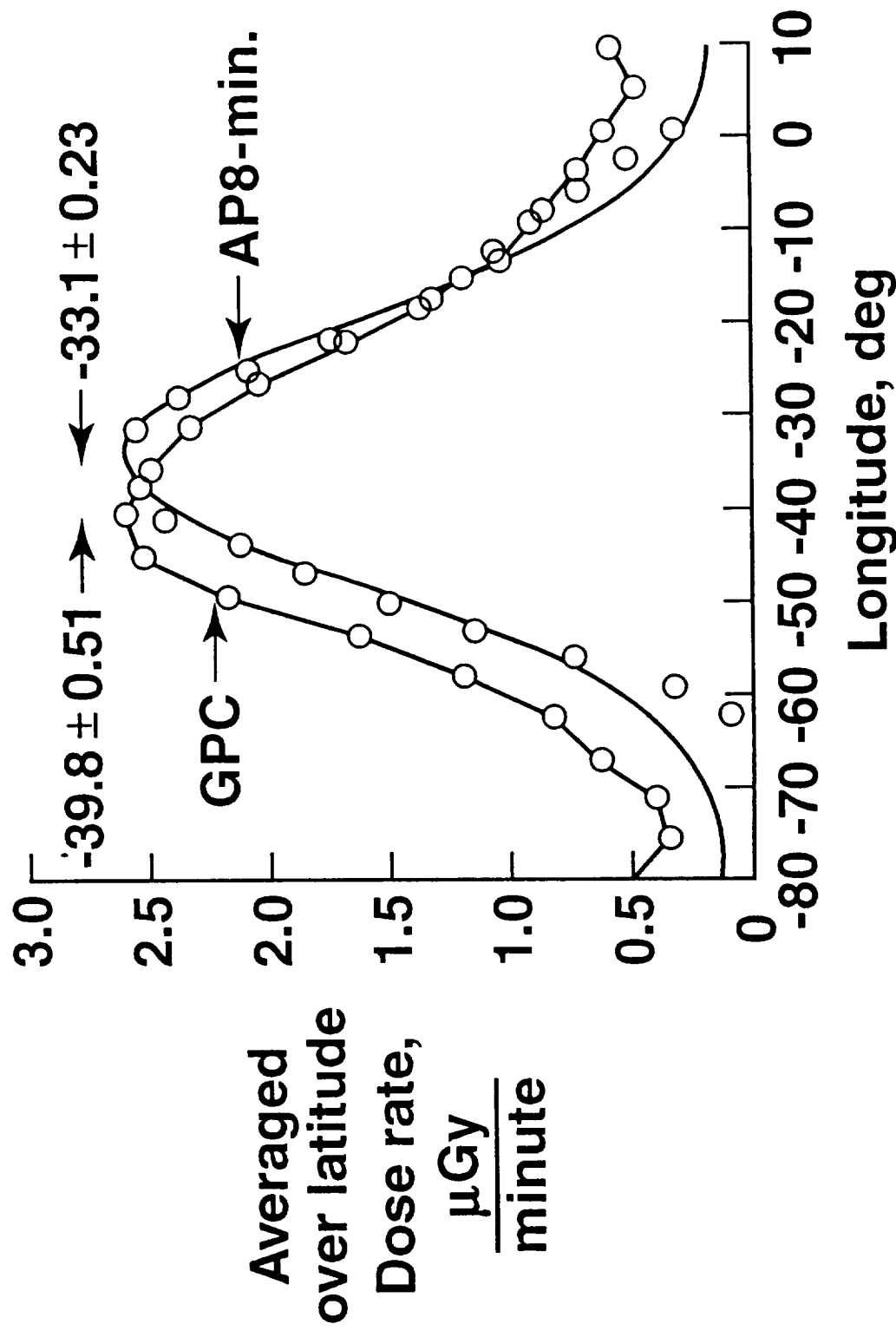
Free Space GCR Spectrum At 1977 Solar Minimum



GPC MEASURED DOSE RATE FOR STS-51 MISSION 28.5°, 290 km altitude

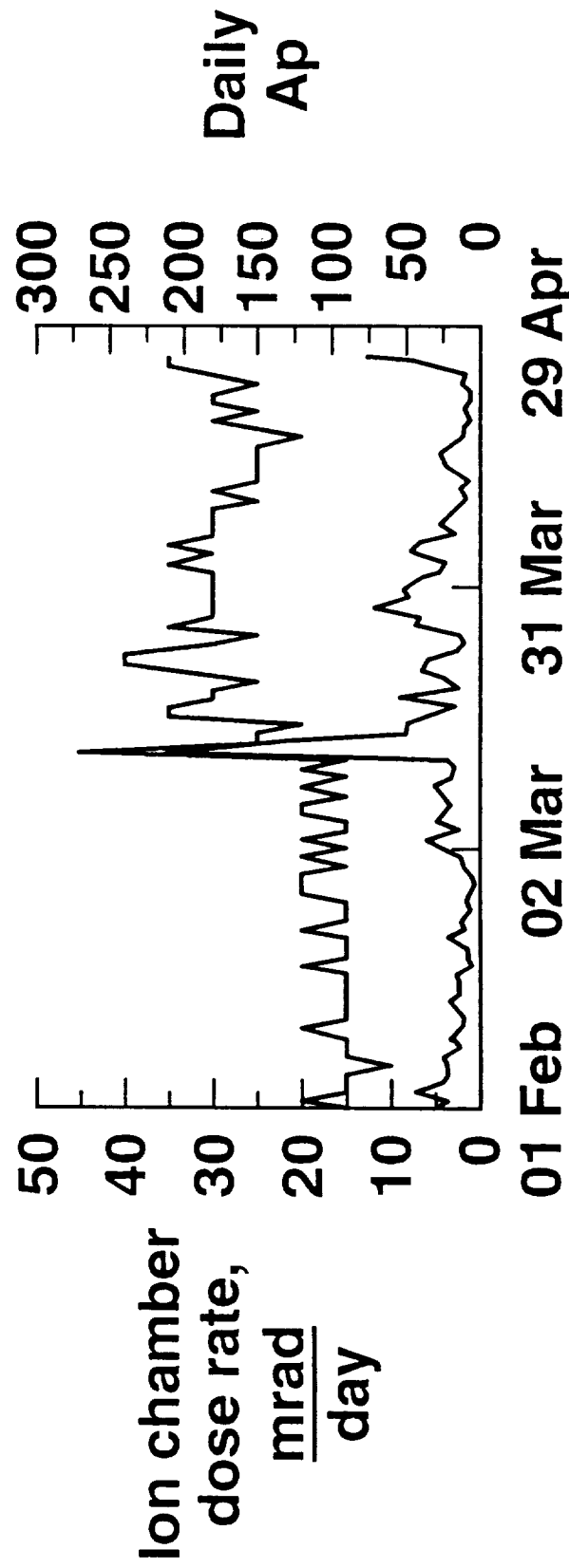
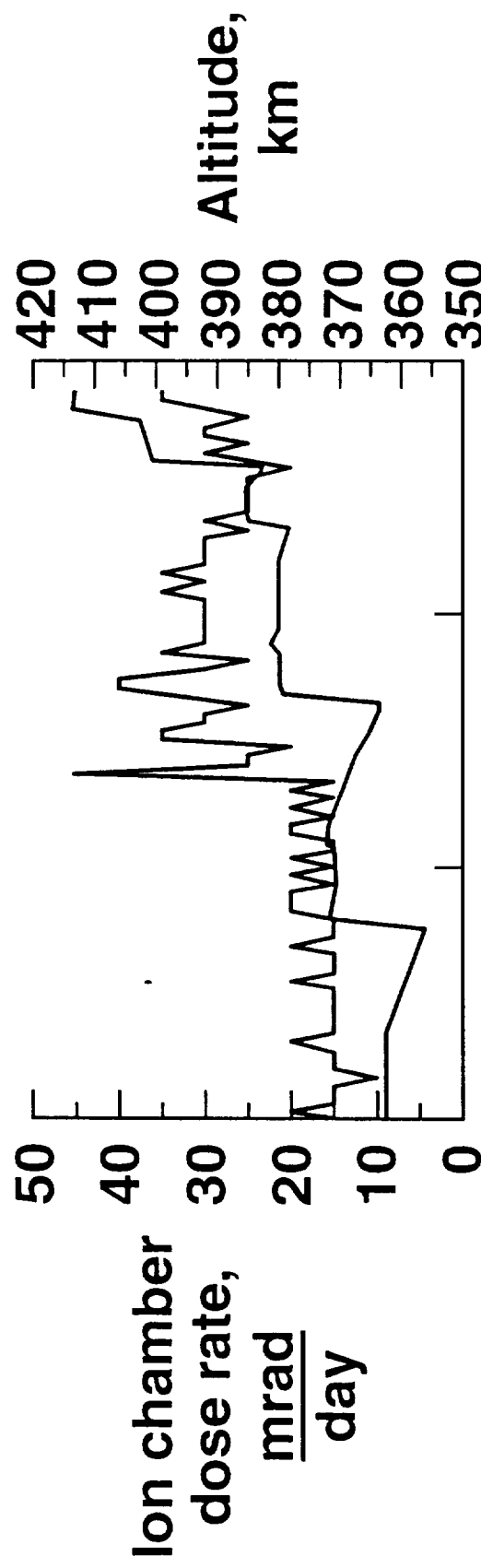


COMPARISON OF MEASURED DOSE RATE ON STS-60 WITH AP-8 MODEL IN THE SAA REGION

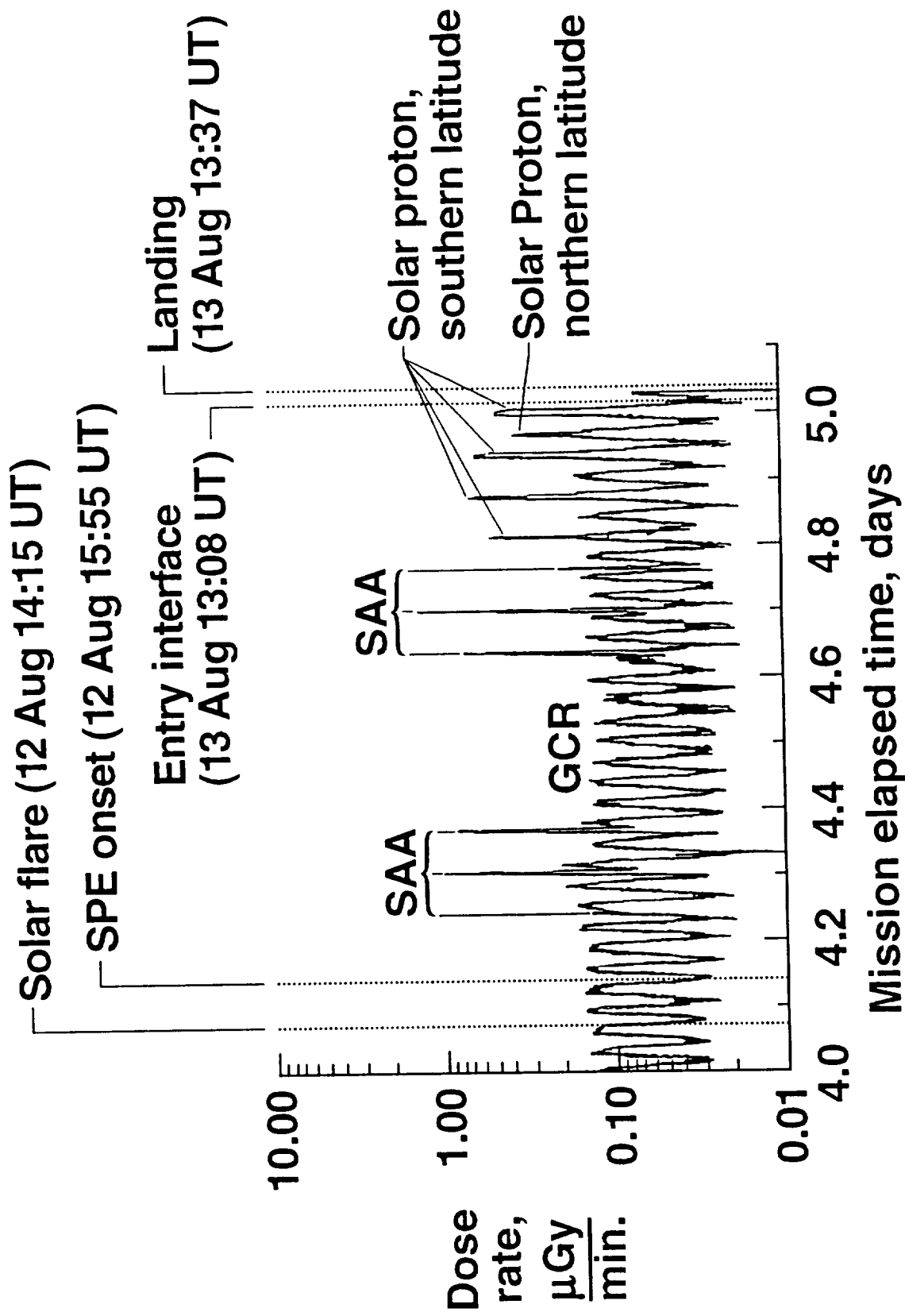


MARCH 1989 SOLAR/GEOMAGNETIC ACTIVITY

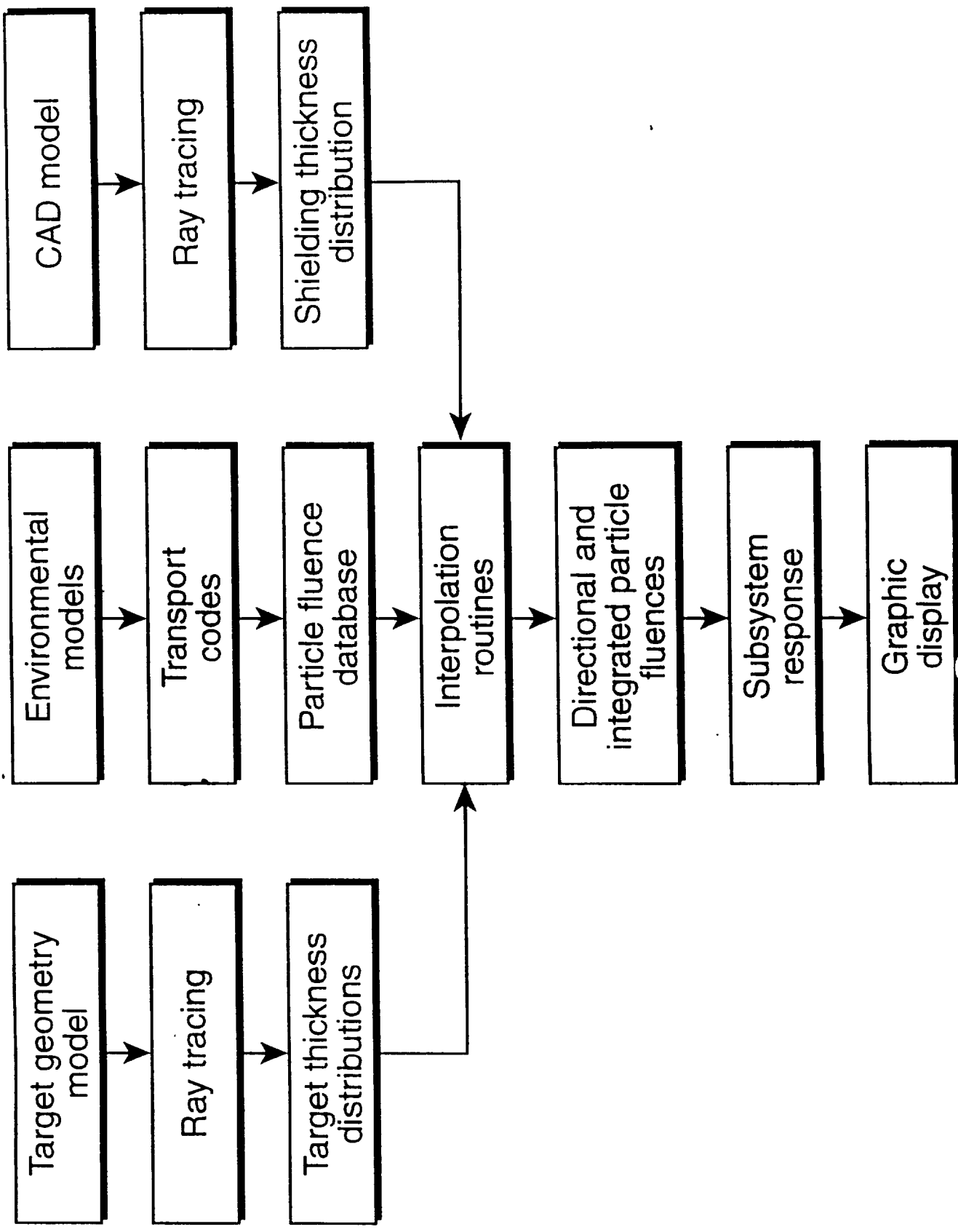
Exposure enhancement aboard Mir (51.6° inclination)



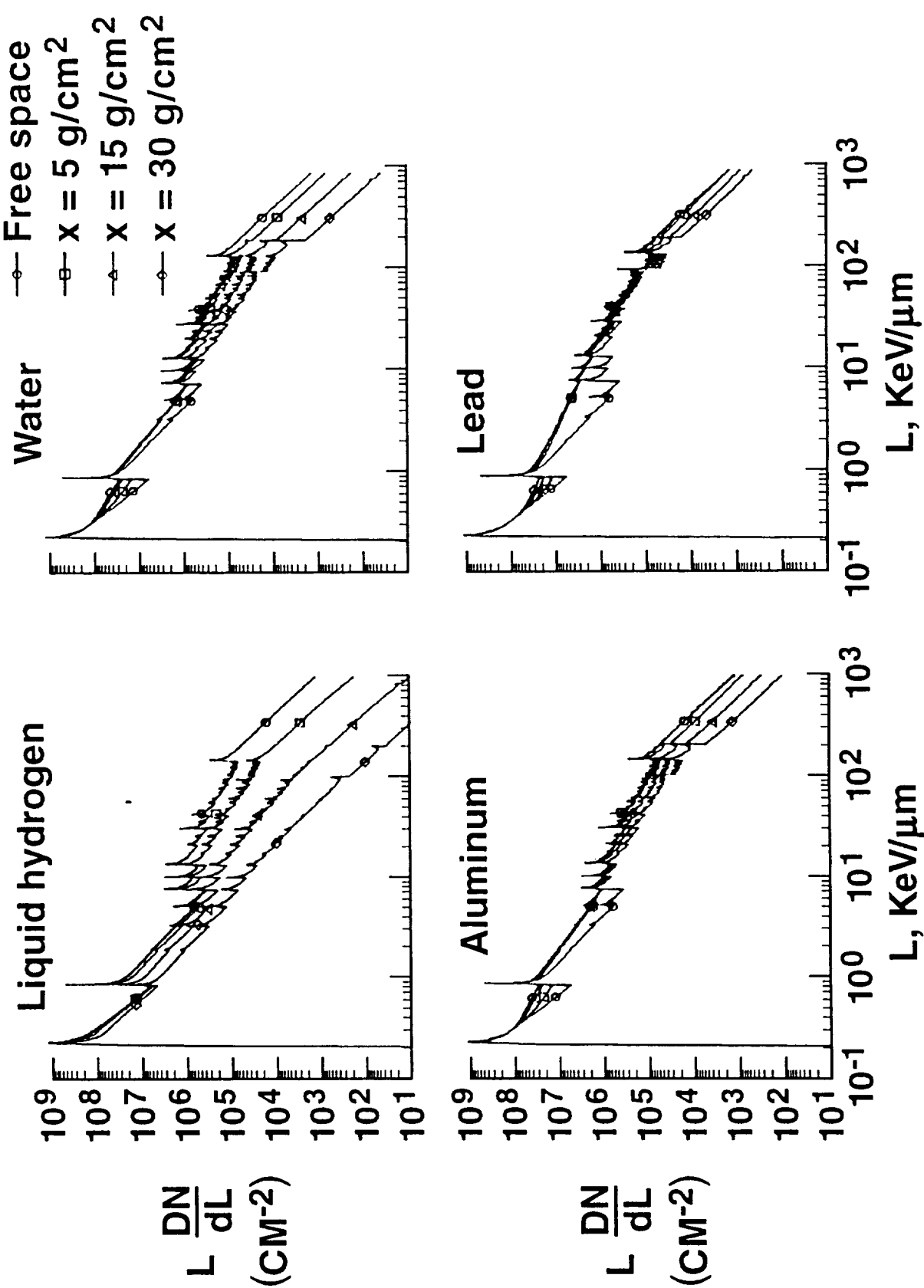
DOSE RATE ON STS-28 DURING AUGUST 89 SPE 57° inclination orbit, 4-channel Air Force TEPC



CALCULATION PROCEDURE FOR SPACECRAFT EXPOSURE ANALYSES



GCR TRANSMISSION CHARACTERISTICS IN VARIOUS ABSORBERS



SAGE III DETECTOR SHIELD DESIGN ANALYSIS

OVERVIEW

- SAGE III (Stratospheric Aerosol and Gas Experiment), a LaRC environmental satellite
- Utilizes calibrated charge couple device (CCD) for optical spectral measurements
- 5-year mission in sun-synchronous orbit at 705 km altitude
- CCD must be protected from ionizing radiation environment

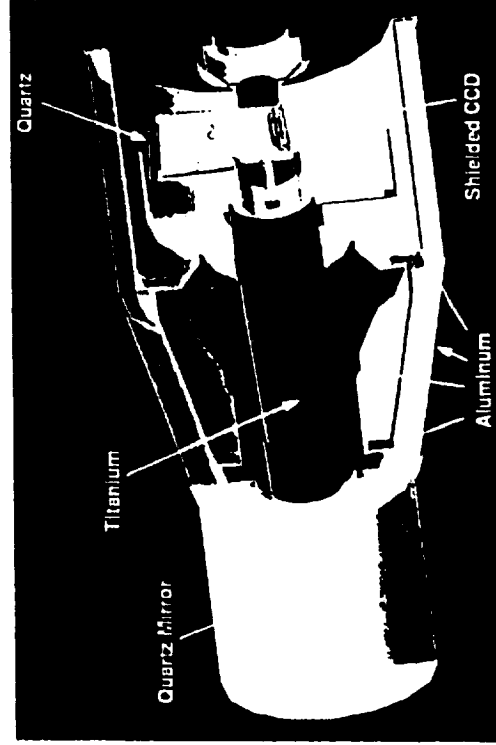
RADIATION EXPOSURE OF SAGE III

Objective: To evaluate direct interference and long-term degradation of SAGE-III CCD as a result of exposure to high-energy nucleons

Approach:

- Generate detailed CAD solid model of SAGE-III instrument
- Define high-energy, charged-particle environment found in Earth orbit
- Transport environment particles through spacecraft structural materials
- Evaluate exposure of detector for primary protons and secondary protons and neutrons
- Estimate degradation of CCD in terms of charge transfer inefficiency produced by lattice displacements

CAD MODEL OF SAGE-III INSTRUMENT



RESULTS

CAD solid model essential in providing detailed directional exposure distribution

Final shield design impact:

- Principal shield enclosure reduced in mass
- Dedicated shield material changed from tantalum to aluminum
- Additional shielding placed near spacecraft wall
- Final detector sensitivity degradation predicted to be 20% for 5-year mission

CLOUD AND FEATURE EDITING(*CAFE*) TECHNOLOGY DEMONSTRATION EXPERIMENT

SSTI-*LEWIS* WORKSHOP

TRW-Space Park, Redondo Beach, CA

8-9 August 1996

**Dr. Harry F. Benz
SRB/FETD/IOG/LaRC
for**

**R. E. Davis, R. G. Wilson, R. L. Jones
NASA-LaRC**

CAFE TECHNOLOGY DEMONSTRATION EXPERIMENT

CONTENTS

- PURPOSE, SCOPE, ASSUMPTIONS, AND APPROACH
Focus: Automatic cloud/feature algorithm development and testing
- ALGORITHM PHYSICAL BASIS AND RATIONALE
- CAFE ALGORITHM EVOLUTION
- ALGORITHM CHARACTERIZATION
 - Four-Algorithm Suite, evaluated in parallel
 - Editing capability
- ALGORITHM PERFORMANCE ON SYNTHETIC DATA
 - Metrics
 - Preliminary results on 23-scenario set
 - Complexity Assessment(for real-time implementation)
- PRELIMINARY CONCLUSIONS
- SUMMARY STATUS/PLANS

PURPOSE, SCOPE, ASSUMPTIONS, APPROACH

PURPOSE:

- Use *Lewis* HSI multispectral imagery, to perform on-ground, non real-time evaluation of multispectral algorithm concepts for detecting clouds' presence in multispectral Earth-resource imagery.

SCOPE:

- Multi-year study effort

Application:

- Ultimate real-time, autonomous use aboard satellites, for detecting cloud -obscured imagery , and suppressing its transmission to Earth. Payoff is economies in data transmission and archival.(Over 50 % of Earth covered by clouds)

ASSUMPTIONS, CONSTRAINTS, "MINDSET":

- Earth-resource application viewpoint adopted-- i.e. clouds are "contaminants", not objects of study.
- Mimic simple,autonomous operation :
 - Use on-board sensor data only(HSI). No ancillary data(e.g. LWIR from wx satellites) to be used.
 - Assume no a-priori knowledge of pixel terrain type available for use in "cloud masks".
- No night-time operation(No thermal IR)
- Pixel location, satellite ephemeris available, for calculating solar illumination angles.

APPROACH:

- "Consumer Reports"- type evaluation-in-parallel of several relatively simple CAFE algorithm concepts, within above constraints, using *success, failure, false-alarm* metrics.
- Assess what each concept can contribute, within above constraints.
- Assess improvements possible, with relaxed constraints(e.g., adding thermal IR channels)

ALGORITHM PHYSICAL BASIS AND RATIONALE

- Reflectance of substances in the visible and NIR differs, varies with wavelength(e.g., see Fig. 1).
- Reflectance-based parameters can be developed to discriminate substances using multichannel imagery. Examples are ratios and sums of signals in different channels, or apparent reflectances derived from the signals.
- These parameters can be implemented in algorithms.(See Fig. 2 for example)
- Atmospheric transmission varies with wavelength. Atmospheric opacity in some wavelength regions precludes "seeing the surface". This "masking out of the surface" in itself can be used in simple algorithms to detect high-altitude clouds.
- Other "masks" can be developed to discriminate lower altitude clouds against a variety of terrestrial backgrounds.
- We have been advised that *real-time, autonomous detection of clouds against all backgrounds* is at present impossible.
- Nevertheless, with more than 50% of Earth covered with clouds , it is worthwhile to seek some alleviation in the volume of useless (cloud-contaminated)data that is being gathered. Therefore, although doing the "whole job" is considered impossible, we want to assess what level of alleviation is possible, even with simple approaches.

CAFE ALGORITHM EVOLUTION

1. MMA - LaRC FILE EXPERIMENT(1980s):

- Uses V0.65/V0.85, the ratio of the signals in 0.65 and 0.85- μ m channels, to classify a pixel, using thresholds and slopes in a boundary approximation algorithm. (See Fig. 2)
- Flown successfully on Space Shuttle and aircraft, in 1980s, with ~ 80% success rate
- Requires only approximate knowledge of sun zenith angle.
- Clouds, snow, and ice all classified in one category, no discrimination possible. This still useful at low latitudes
- (This concept is the being implemented on SSTI *Clark*. There, the two channels of the WV Imager are processed in real time).

2. ADVANCED FILE CONCEPT(LATE 1980s):

- Adds 1.25 and 1.55- μ m channels to basic *FILE*. to add further discrimination:
 - V065/V155 discriminates cloud from snow or ice.
 - V065/V125 discriminates snow from ice.
- Not yet flown. Presented as our first concept for Lewis *CAFE*, Fall,

1994

CAFE ALGORITHM EVOLUTION, CONT'D.

3. "CLOUD MASK" / APPARENT REFLECTANCE-BASED APPROACHES (SPRING, 1995)

- Based on "cloud masks" being developed for LaRC CERES project. Object: reliable cloud detection("masking") against specific, known terrestrial background types.
Application: Cloud/climate research.
- Operates on derived apparent reflectances; this gives valuable physical insight into likely makeup of background surface. Downside: requires accurate solar zenith angle .
- Masks were developed, recommended under study contract by Dr. B. C. Gao, Univ. Space Research Inst./NASA-GSFC to detect:
 - High Altitude clouds(cirrus) over any background.
 - Clouds over water.
 - Clouds over snow or ice.
 - Clouds over vegetation.
 - Clouds over bare land.
- Application to *Lewis CAFE* :
 - Most valuable element is high-altitude cloud (HAC) logic(1.38, 1.88- μ m channels):
 - HAC grafted into other algorithms, too, as high-altitude cloud preprocessor.
 - Much other Gao logic incorporated into test algorithms
- This hybrid algorithm concept first briefed at TRW ICDA Jan. 1995

4. ALGORITHM SUITE- EVALUATION IN PARALLEL (Summer, 1996):

- Concept evolved summer 1995 of evaluating candidate algorithms approaches in parallel("Consumer Reports" approach) in ground processing of registered HSI data, using three metrics: *success, failure, false-alarm.*
- In Spring 1996 added JPL *INCM* cloud detection approach to evaluation list.
- Result: The current Four-Algorithm CAFE suite for Lewis, described in Tables 1, 2

SPECTRAL REFLECTANCE OF VARIOUS TARGETS

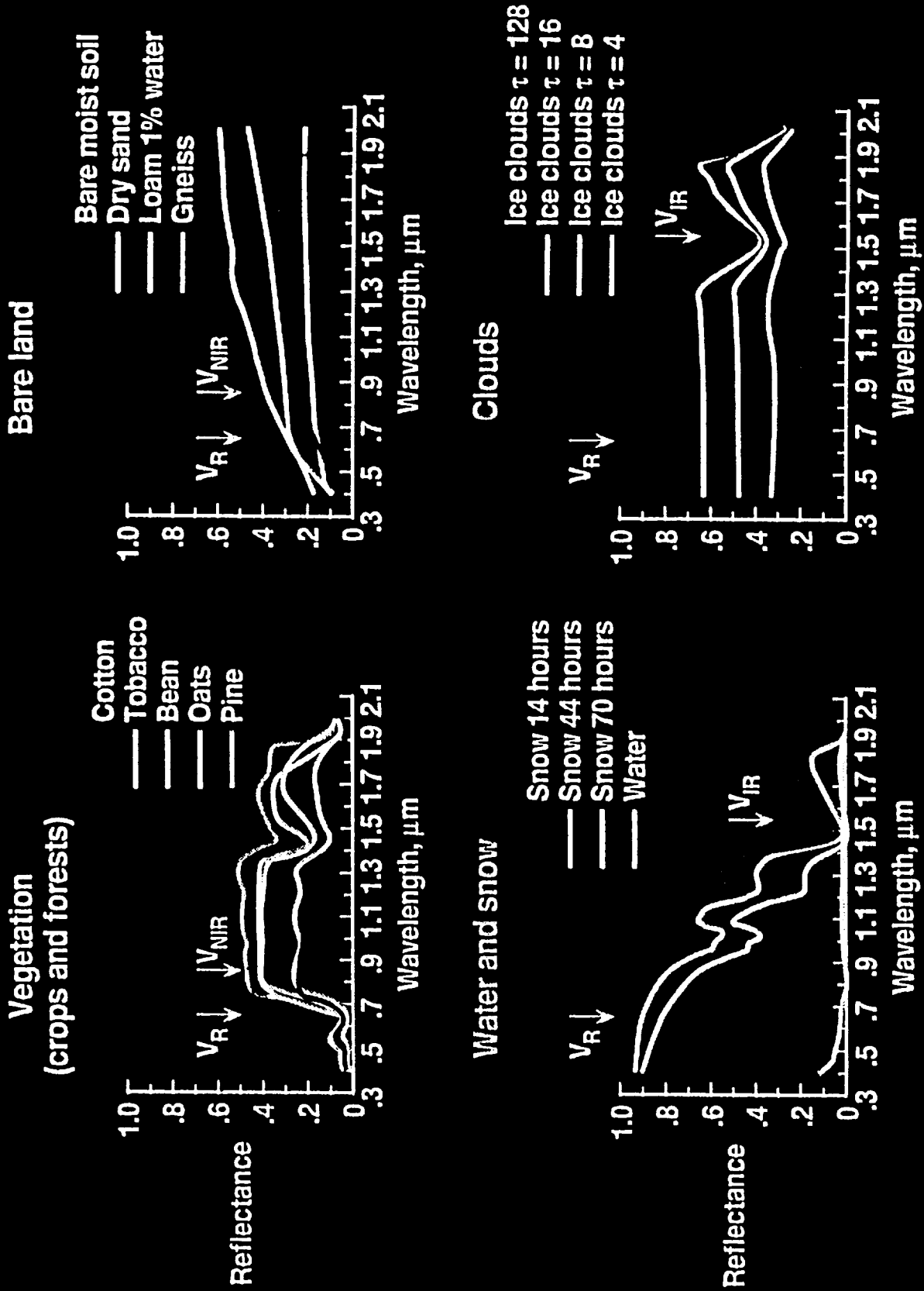
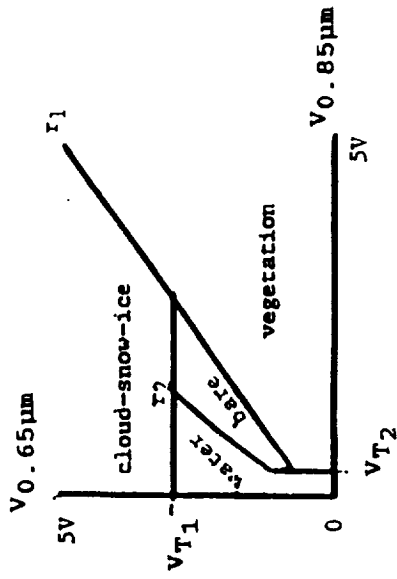


Figure 1

Figure 2 CLOUD/FEATURE IDENTIFICATION ALGORITHM (ADVANCED FILE CONCEPT)

(a) INITIAL CLASSIFICATION FOR ALL PIXELS



$V_{T1} = 1.15V$ for low sun angle

$V_{T1} = 1.90V$ for high sun angle

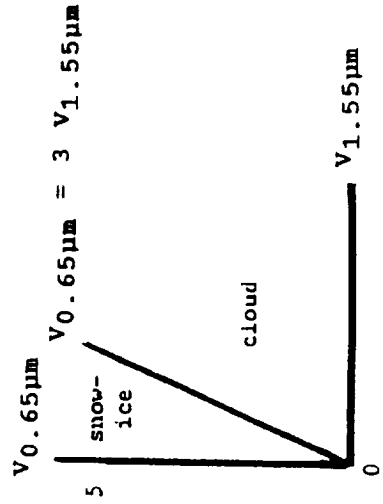
$V_{T2} = 0.45V$ for low sun angle

$V_{T2} = 0.73V$ for high sun angle

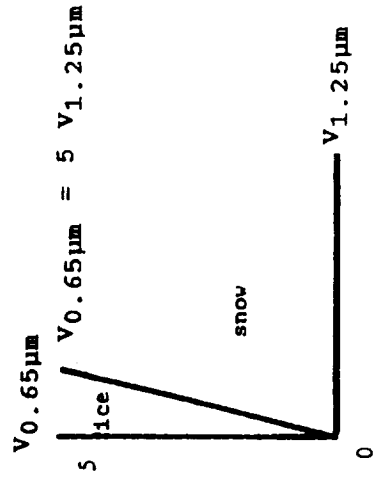
$r_1: V_{0.65\mu m} = 0.694 V_{0.85\mu m} + b_1 \quad b_1 = 0.2 \text{ Volts}$

$r_2: V_{0.65\mu m} = 1.18 V_{0.85\mu m} + b_2 \quad b_2 = 0.1 \text{ Volts}$

(b) CLASSIFICATION BETWEEN CLOUD AND SNOW/ICE PIXELS



(c) CLASSIFICATION BETWEEN SNOW AND ICE PIXELS



ALGORITHM CHARACTERIZATION

ALG. 1:

- Most complex, provides max. physical insight via apparent reflectance (8 editing/classification outcomes)
- Accurate solar zenith angle (SZA) needed for apparent reflectance
- Stringent "success" criterion: cloud detection, plus feature ID

ALG. 2:

- Alg. 1 simplified, to indicate only cloud presence/absence(3 outcomes)
- May fit basic needs of majority of users
- Relaxed success criterion

ALG. 3:

- More empirical than Alg. 1, less physical insight(7 outcomes)
- Only approximate SZA needed
- Stringent success criterion
- Builds on *FILE* research

ALG. 4:

- JPL Image Navigation Cloud Mask(for detecting landmarks, even through thin clouds)(3 outcomes).
- To be flown 1997
- Outcomes : "Cloudy", or "Clear Enough". May fit needs of majority of earth-resource users. Relaxed success criterion.
- Should be included in *CAFE* evaluation
- 0.65, 0.85 μm channels only
- Low Cloud/snow/ice cannot be discriminated

TABLE 1

SSTI Lewis CAFE ALGORITHM SUITE

ALGORITHM:	NO. CHANNELS	CLASSIFICATION OUTCOMES:	0.66 μm	0.86 μm	1.25 μm	1.38 μm	1.55 μm	1.88 μm	2.13 μm
<u>1</u> Multi-Channel Reflectance Algorithm (Based on Gao's research, augmented by AFGL snow/ice discrimination)	6	High-Alt. Cloud Low-Mid-Alt. Cloud Vegetation Vegetation/land mix Clear ocean Clear lake or coast Ice Snow	X	X	X (A)	X		X	X
<u>2</u> Streamlined Version of 1 (clouds present/absent only)	5	High-Alt. Cloud "Cloudy" "Cloud-free"	X	X		X		X	X
<u>3</u> Advanced FILE ¹ , Augmented by Gao's HAC ² logic	6	High-Alt. Cloud Low-Mid Alt Cloud Vegetation Bare land Water Ice Snow	X	X	X	X (A)	X	X (A)	
<u>4</u> INCM ³ , Augmented by HAC logic	4	High-Alt Cloud Cloud/Ice/Snow "Clear Enough"	X	X		X (A)		X (A)	

Notes:

A Denotes augmentation of original algorithm concept

1 Feature Identification and Location Experiment

2. High Altitude Cloud

3. Image Navigation Cloud Mask (DiGirolamo/Davies, 1995)

TABLE 2

EDITING CAPABILITY OF *CAFE* ALGORITHMS

EDITING OUTCOME:	ALG. 1	ALG. 2	ALG. 3	ALG. 4
HIGH ALT.CLOUD	X	X	X	X
LOW-MED. ALT. CLOUD	X	X	X	
CLOUD-FREE		X		
"CLEAR ENOUGH"				X
WATER			X	
CLEAR OCEAN	X			
CLEAR LAKE	X			
VEGETATION	X		X	
VEGETATION/SOIL MIX	X			
BARE SOIL			X	
CLOUD/SNOW/ICE (UNDISCRIMINATED)				X
SNOW	X		X	
ICE	X		X	

ALGORITHM COMPLEXITY ASSESSMENT

(For real-time procesing of image of $m \times n$ pixels)

ALGORITHM	# OPERATIONS ¹	SPACE REQUIREMENT	TIME(SEC.) ²
1	26	$7 mn + 8$	2.1
2	22	$6 mn + 6$	1.9
3	26	$7 mn + 7$	1.2
4	19	$5 mn + 5$	4.4

1. Adds, multiplies, divides, ratios, exponentiations, etc
2. Simulations with 60 Mhz *sparc20* on 512×512 - pixel image.

PRELIMINARY CONCLUSIONS, FROM INITIAL TESTING ON SYNTHETIC DATA

- All tested algorithms have comparable success and false alarm rates.
- Greatest difficulty is in ID of bare land(may get identified as cloud, causing false alarm). Needs further research, refinement.
- Further research on ice/snow discrimination is needed.
- High altitude cloud logic particularly valuable, for speeding rejection of cloudy scenes.
- All algorithms computationally efficient. Alg. 3 appears fastest, Alg. 4 slowest.

SUMMARY STATUS/PLANS

STATUS :

- Four algorithms presently in Lewis CAFE suite
- Algorithms coded in C++ with preliminary constants
- All algorithms tested on *MODTRAN* -generated synthetic data (23 cloud/clear background scenario set), using success/failure/false-alarm metrics
- Algorithm complexity assessed, for future real-time application

PLANS:

- Update algorithm constants using HSI instrument characteristics as available
- Test algorithms on real imagery(AVIRIS, Landsat) accompanied by ground truth data
- Develop logic for shadows
- Arrange to receive USAF RTNeph cloud truth data to validate algorithms during SSTI missions.

Advanced Packaging Experiment (APEX)

**SSTI - Lewis Workshop
August 9, 1996**

**Tom Borden (JPL)
John Beahan (JPL)
Rudy Almeida (TRW)**

APEX Overview

- NASA JPL sponsored experiment
 - JPL developed all slice hardware and software
 - Leveraged RH32 Multi-Chip Module jointly developed by JPL and TRW under NASA Technology Affiliates Program
- APEX experiment housed and powered by TRW built Payload Electronics Assembly (PEA)
- Experiment will collect data related to advanced packaging approaches and cryocooler accelerometer data using TRW RH32 processor

APEX Mission

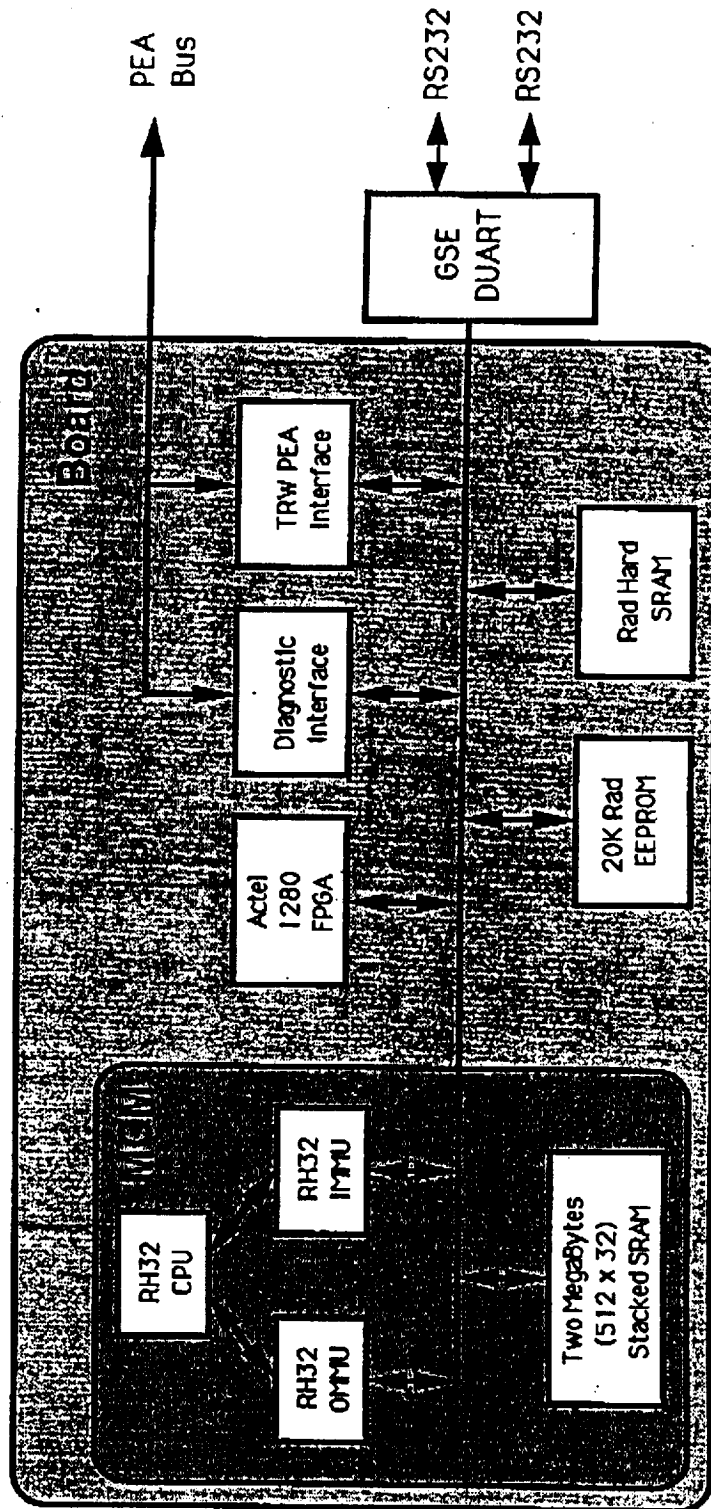
- Demonstrates application of advanced packaging technologies for space
 - Large (2" x 4") MCM package to allow maximum integration
 - Stacked SRAM dice within MCM
 - Inorganic silicon substrate providing high interconnect density
- Demonstrates self contained computer subsystem in space environment
 - Uses hardened TRW RH32 chipset as processor core
 - Incorporates all processing, memory and I/O functions into a single SEM-E (5.8" x 3.8") board

APEX Mission (con't)

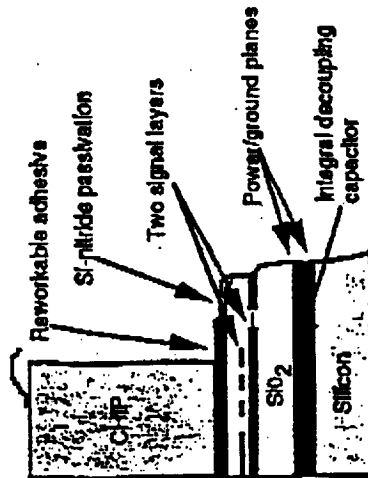
- Determines and downlinks enhanced cryocooler accelerometer data
 - Processes both cryocooler's accelerometer data and provides vibration telemetry. Before APEX, we were only able to get the peak to peak accelerometer envelope
 - I/O card can connect either HSI or LEISA accelerometer data to APEX at two levels of gain
 - Uses the same FFT algorithm developed to control vibration of the cryocoolers
 - Determines the gain and phase of the 60Hz fundamental and 15 harmonics
- This telemetry will greatly enhance knowledge of cooler operation over life and temperature

APEX: Advanced Packaging Experiment for LEWIS SSTI Spacecraft

APEX Design Block Diagram



nCHIP MCM-D Technology



nC1000 Substrate Cross-Section

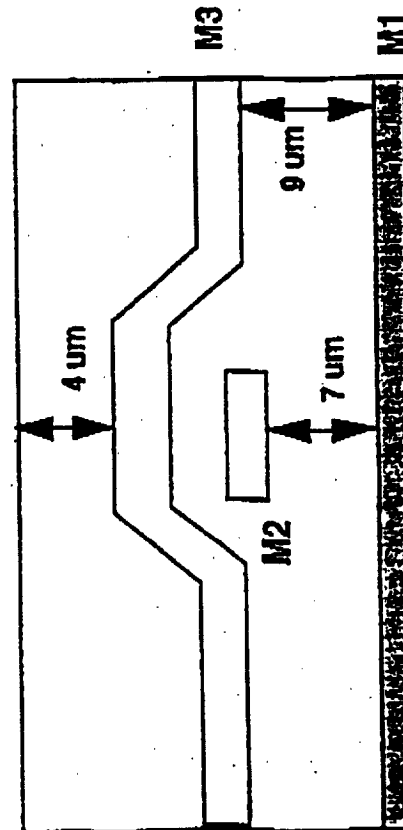


Table 1. nCHIP MCM-D Characteristics

Materials:

Substrate Si

Dielectric (PECVD) SiO₂, $\epsilon = 3.75$ (at $f > 1\text{MHz}$)

Interconnect metal A1

Die attach Thermal epoxy

Decoupling capacitor Anodized alumina (A1203)

Interconnect Dimensions:

Power/ground and 2 signals MO, M1, M2, M3

Signal metal width 10 um (min)

Signal metal height 2 um (min)

Signal metal space 15 um (min)

Metal pitch 25 um (min)

Via pitch 35 um (min)

Via diameter 5 um

Electrical Parameters:

Signal layer resistance 15 mohm/square

Integral decoupling C 50 nF/sq. cm

Low Inductance wire bounding 1.2 nH

Thermal Parameters:

Thermal resistance 0.17 cm² C/W

Temperature coefficient of A1 0.4 %/C

Mechanical:

Stress x

Chemical:

Moisture absorption low

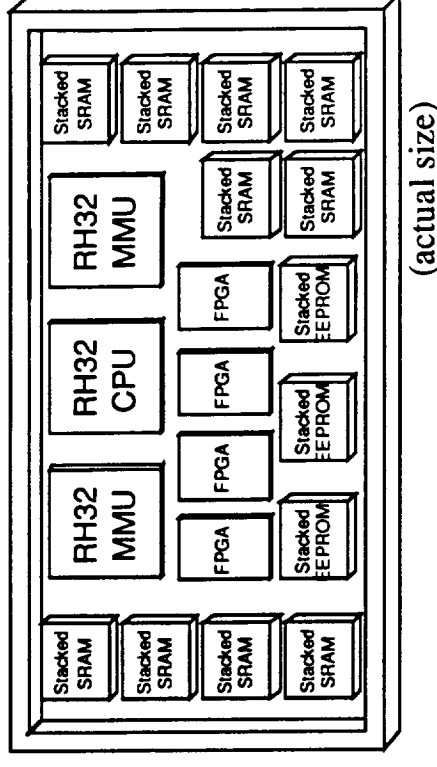
Outgassing low

January 6, 1995

RH32 Multichip Module Computer

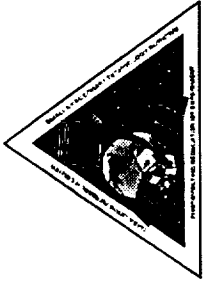
Features

- Complete RH32 based computer in a single package
- Extensive user re-configurable I/O
- Expandable via system bus interface
- Highly testable and configurable due to careful partitioning of module functions
- MCM-D silicon-on-silicon substrate technology with only 2 layers of interconnect
- Advanced packaging using stacked die technology for RAM and EEPROM memory
- No glue logic, no pull-up resistors and no capacitors needed
- All memory incorporates error detection and correction
- RH32 MCM has been extensively tested in a full system level simulation environment
- Power and performance scale with frequency



Performance

- Throughput: 20MIPs
- Power: 10W (@25MHz)
- Size: 2" x 4" x .16"
- Weight: 3 oz.
- Memory: 2 MB static RAM
1/2 MB nonvolatile EEPROM
- Package: 442 lead quad flat pack



Photovoltaic Regulator Kit Experiment

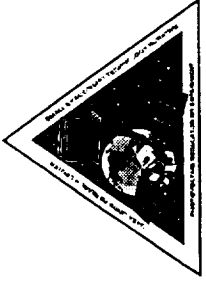
August 9, 1996

Tony Baez
NASA Lewis Research Center
Power Technology Division
21000 Brookpark RD
Cleveland, Ohio 44135
Phone: 216-433-5318
Email: Anastacio.Baez@Lerc.NASA.Gov



Outline

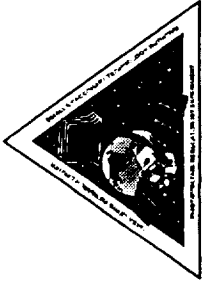
- Background
- PRKE Objectives
- Experiment Success Criteria
- PRKE Description
- Development Approach
- Next Logical Step



Background

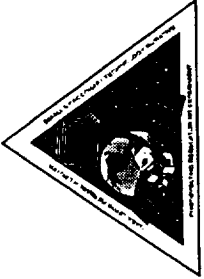
Why PRKE ?

- Alternate architecture for Space Station Freedom resulted in a unique patented power source regulator.
- Series connected boost concept extended to satellite systems with the successful development of the TROPIX test bed.
- TRW recommended that SCBU concept be further developed and demonstrated as a tech demo on the SSTI program.
- PRKE late start required aggressive and compressed design/build/test cycle.



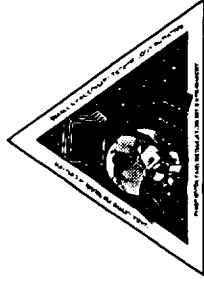
PRKE Objectives

- Demonstrate operation in low earth orbit of the main building block of a low cost, highly efficient, fault tolerant electric power system.
- Help validate commercial off-the-shelf DC-DC converters for use in PV regulator systems.
- Help mitigate risk associated with using off the shelf commercial technology to build spacecraft power systems.
- Provide long term performance data in LEO for the Series Connected Booster Unit.



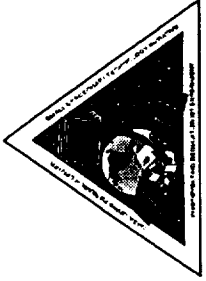
Experiment Success Criteria

- Operate PRKE in LEO
 - Minimally Successful
 - Meet launch date
 - Retrieve operational data
 - Successful
 - Operate experiment for at least three months
 - Retrieve performance data (Execute PRKE Test Matrix)
 - Highly Successful
 - Operate experiment for one year (mission)
 - Execute PRKE Test Matrix BOL and EOL
 - Match Baseline Performance Data



PRKE Description

- PRKE is a complete photovoltaic power regulator built using commercial off the shelf power supplies.
- PRKE main components are a Series Connected Booster Unit, a control system element, and an electronic power re-circulator.
- The SCBU is the test specimen in PRKE.
- SCBU main functions
 - Provide regulated current to energy storage system.
 - Voltage regulator for user loads requiring tightly regulated power.

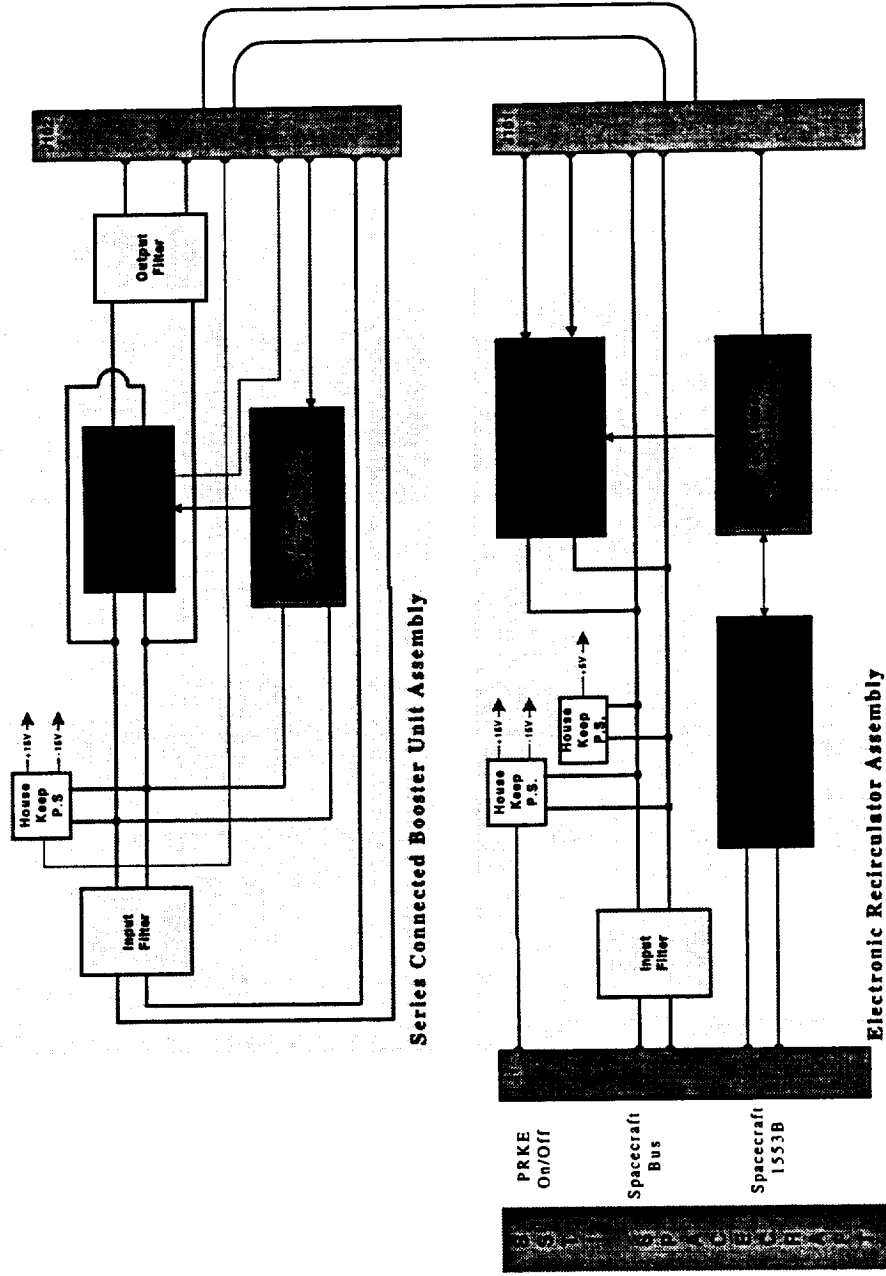


PRKE Description, cont.

- The control element provides 1553 data bus interface functions and control signals to other PRKE components
- The electronic re-circulator is a programmable load that allows the SCBU to be tested at power levels above the levels allocated by the SSTI spacecraft.
 - It accomplishes this by feeding the SCBU power back to its input in a closed loop operation.

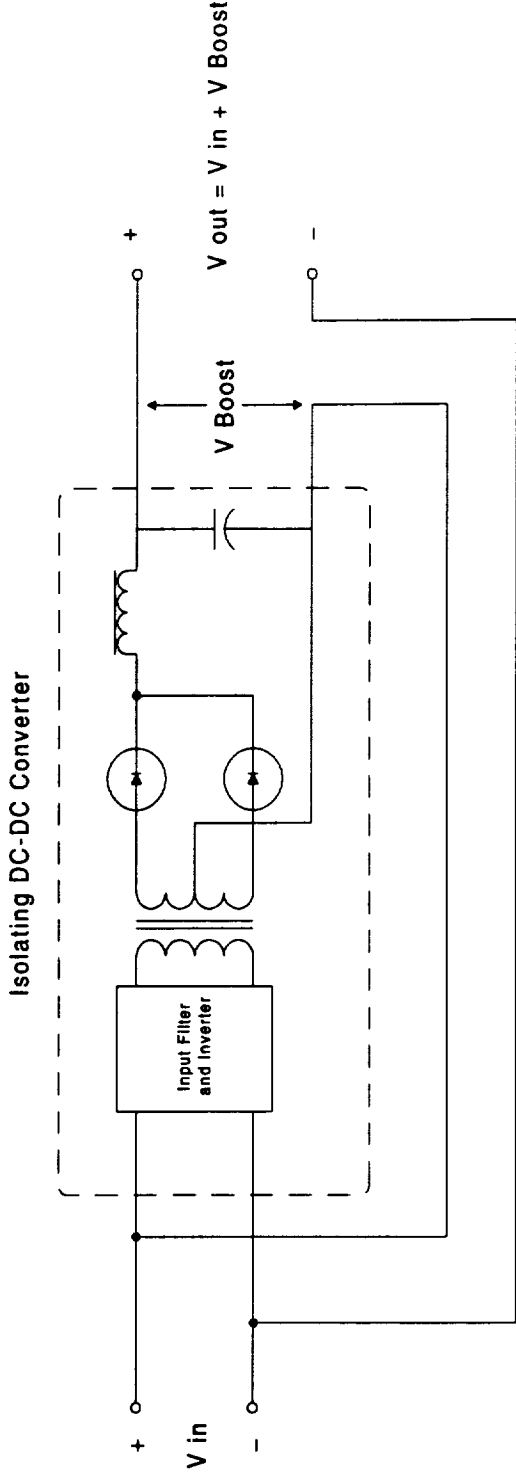


PRKE Description, cont.





SCBU Concept



DC-DC Converter Specs

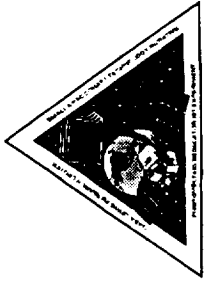
Input: 16-40 Volts
Output: 12 Volts @ 5 amps (60 Watts)
Efficiency: 85 %

SCBU (Zero Boost)

Input: 38 Volts
Output: 38 volts @ 5 amps (190 Watts)
Diode losses = $5 \times .7 = 3.5$ watts
Fixed losses = 2.5 watts
Total fixed losses = 6 watts
Efficiency = $190/196 \times 100 = 96.9 \%$

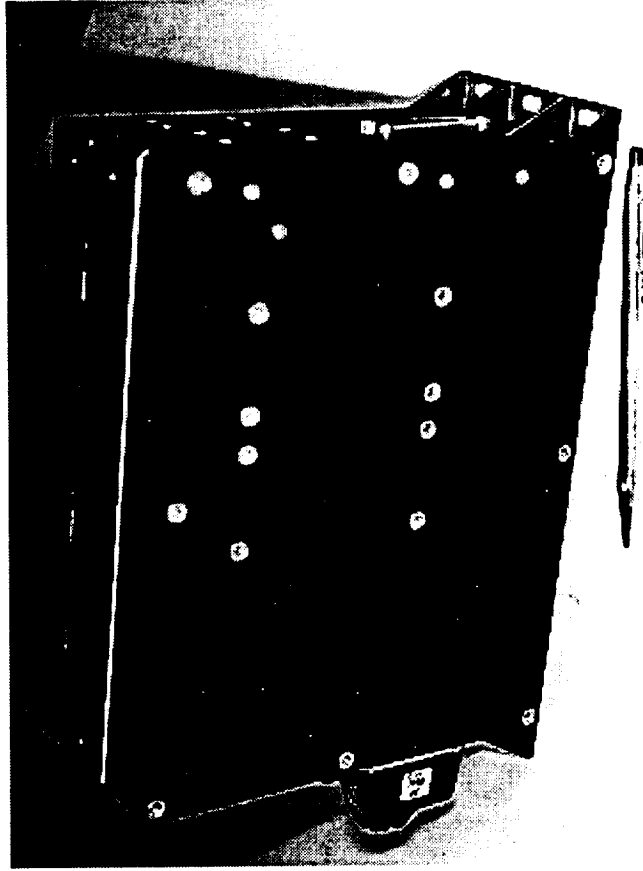
SCBU (12 Volts Boost)

Input: 26 Volts
Output: 38 volts @ 5 amps (190 Watts)
Converter losses = $(12 \text{ V} \times 5 \text{ A}) = 60$ watts
85 % Efficiency = 10.5 watts losses
Total losses = $6 + 10.5 = 16.5$ watts
Efficiency = $190/206.5 \times 100 = 92 \%$



PRKE Description, cont.

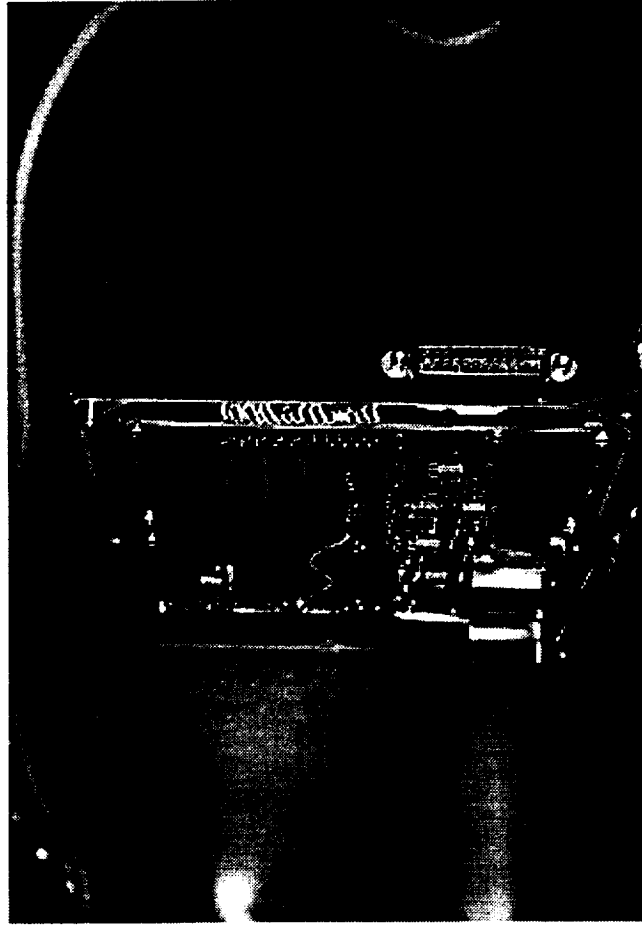
PRKE Experiment

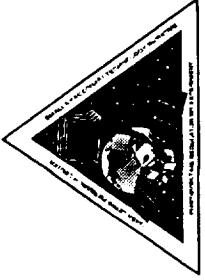




PRKE Description, cont.

SCBU Slice





PRKE Description, cont.

○ Requirements

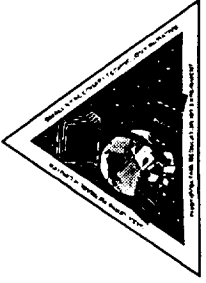
- Power
 - PRKE requires a 28VDC input rated at 40 watts max..
- Thermal
 - Thermal dissipation is no more than 40 watts.
- Size
 - 3.2" x 6.5" x 9.35"
- Mass
 - 5 lbs
- Commands/Telemetry
 - Spacecraft OBC 1553B Data Bus.



Development Approach

○ PRKE Chronology

- Proof of Concept Demo - 12/94
- PRKE accepted as SSTI experiment - 1/95
- Interface Control Document - 3/95
- PRKE Breadboard operational - 5/95
- Brassboard operational - 6/95
- Electrical design completed - 7/95
- Mechanical design completed - 7/95



Development Approach, cont.

○ PRKE Chronology, cont.

- Protoflight unit fabrication complete - 9/95
- Protoflight qualification tests complete - 10/95
- Flight unit fabrication complete - 10/95
- Flight unit acceptance tests complete - 10/95
- Flight unit delivered - 11/95
- Spacecraft integration and test - 11/95
- Launch - 7/96



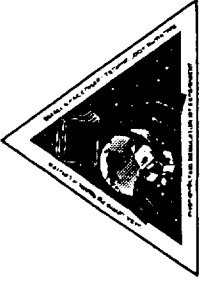
Development Approach, cont.

○ Design strategy

- All electrical design done in-house.
 - Use modified Sundstrand's 1553B card.
- Experiment mechanical design done at TRW.
 - Utilized flight proven packaging - mod to suit PRKE
- Fully exercise design approach with breadboard/brassboard.
 - Identify show stoppers/potential problem areas.

○ Fabrication and Test

- Fabricate and Test qual and flight units in-house.
 - Follow NASA specs/ TRW Specs as guidelines.
 - Housing and PWB contracted out.



Next Logical Step

- Planning advanced PRKE regulator with twice the power density of current design.
- Working with TRW to identify mission to fly PRKE as primary source regulator.
- PRKE regulator design is the baseline for the Air Force Phillips Lab ISUS Program.
 - Fabrication of 600 watt SCBU underway

ENHANCED ACS EXPERIMENT

**P. G. Maghami
NASA Langley Research Center**

August 9, 1996

TECHNOLOGY DEMONSTRATION DESCRIPTION

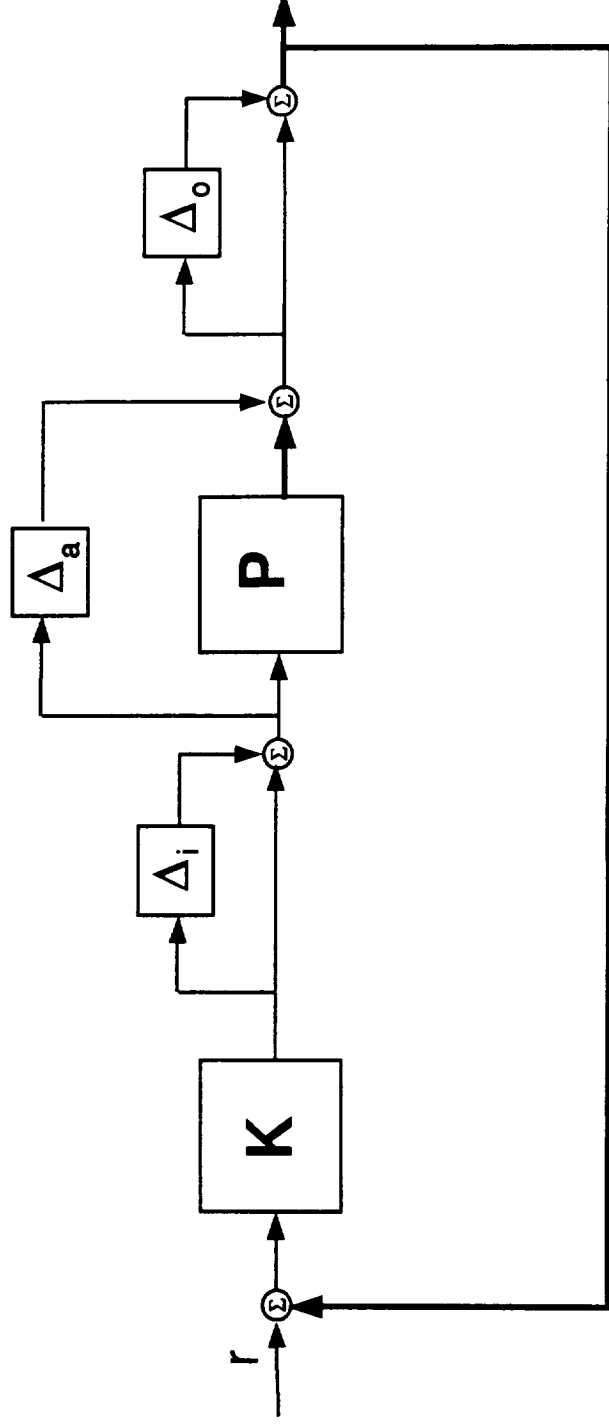
- Develop and implement multi-input/multi-output (MIMO) control designs and algorithms for the Lewis Spacecraft
 - Improved pointing performance
 - Easy implementation and modification of control designs
- The experiment involves the normal mode operation (science mode)
- The experiment would be conducted after the first year of operation
- Develop a software module to implement the MIMO ACS design
- No hardware or software (beyond the addition of the MIMO algorithm) mods required

TECHNOLOGY DEMONSTRATION DESCRIPTION

- Perform, implement, and evaluate MIMO control designs
 - GN&C simulation
 - Flight telemetry data
- The enhanced ACS would be implemented as an additional module within the flight control software
 - The enhanced ACS software would be integrated before launch
 - Upload each ACS design data to conduct experiments

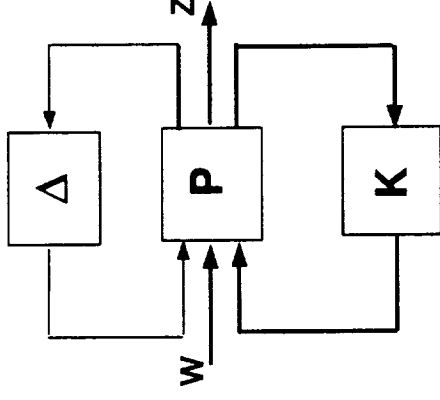
MIMO ACS

- Multi-input/multi-output ACS is designed for concurrent three-axis stabilization
- MIMO designs may take advantage of dynamic coupling
- Modern and robust control theory works mainly with MIMO framework
- Stability margins are imposed through robustness considerations



ROBUST CONTROL DESIGN

- The system and uncertainties are represented in standard form



- Uncertainty may be structured or unstructured
- Design for robust stabilization and/or robust performance
 - Small Gain theorem
 - Stability Robustness theorem
 - Performance Robustness theorem

DESIGN OPTIMIZATION APPROACH

- Use design optimization techniques (nonlinear programming) to synthesize MIMO controllers
- Formulation is based on mixed H_2/H_∞ problem
- Design Variables:
 - Coefficients of the Kalman filter
 - Coefficients of the linear-quadratic regulator
 - Coefficients of the shaping filters
- H_∞ -based constraints to accommodate
 - Input/Output uncertainties
 - Modal frequency uncertainties
 - Unmodeled plant dynamics

MIMO ACS IMPLEMENTATION

- The MIMO enhanced ACS designs are implemented as:

$$z_{k+1} = A_c z_k + B_c y_k$$

$$u_k = C_c z_k + D_c y_k$$

- A_c, B_c, C_c, D_c are system matrices
- y_k represents sensor information provided by the baseline ACS software : attitude and attitude rate
- u_k represents the Momentum command to the reaction wheels
- Any LTI control systems can be easily implemented with this architecture with appropriate A_c, B_c, C_c, D_c matrices: this includes the baseline design as well
- Each MIMO design would provide new A_c, B_c, C_c, D_c matrices
- Implementations are quite systematic and easy to accomplish: upload new set of matrices

SOFTWARE IMPLEMENTATION & REQUIREMENTS

- The enhanced ACS is a self-contained module within the Lewis flight software package
- Any MIMO linear time-invariant controller may be reduced to tridiagonal form with appropriate coordinate transformations
- The memory required is a linear function of the controller order:
 $10n + 25$ to $13n + 34$
- Estimated floating point operations is a linear function of the controller order: $12n + 16$
- A FORTRAN code and a C code implementing the MIMO algorithm have been developed and delivered
 - FORTRAN code used in GN&C simulation
 - C code implemented within the OBC flight software
- Safety switches are implemented to transfer mode to baseline ACS or safe hold mode if anomalies are detected

TESTING & VERIFICATION

- Self-contained MIMO module will minimize implementation and verification efforts and reduce complications
- MIMO designs performed for the PDR and CDR models of LEWIS
- Algorithm and designs verified through simulations
 - LaRC SIMULINK simulation
 - TRW FORTRAN and C simulations
- Three MIMO controllers designed and simulated for the PDR model:
 - A MIMO equivalent to the baseline normal mode: may be used as a back up to baseline normal mode
 - An Enhanced MIMO controller
 - A destabilizing MIMO controller: Tests the safety switches
- Five MIMO controllers designed and simulated for the CDR model

FUTURE PLANS

- Experiment to occur after the first year of S/C operation
- MIMO controller designs and simulations will continue until the flight experiment
 - Robust stabilization and performance
 - Performance trade-offs
 - Subset of designed controllers would be used in the experiment
- On-orbit ID experiment may provide fine tuning
 - Improve model uncertainty
 - Identify modeling deficiencies

GODDARD ELECTRONICS MODULE (GEM)

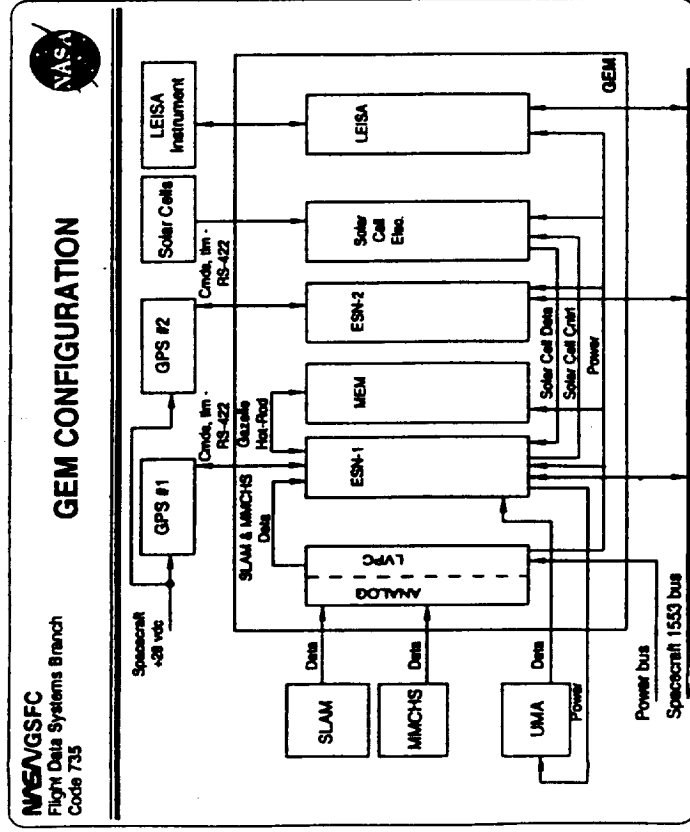
**Philip J. Luers
NASA/GSFC**

**Flight Data Systems Branch
Code 735
Greenbelt, MD 20771**

Philip.Luers@GSFC.NASA.GOV



Goddard Electronics Module (GEM)



1553 Interface for:

- GPS1 & 2
- ASCE
- SLAM & UMA
- MMCHS

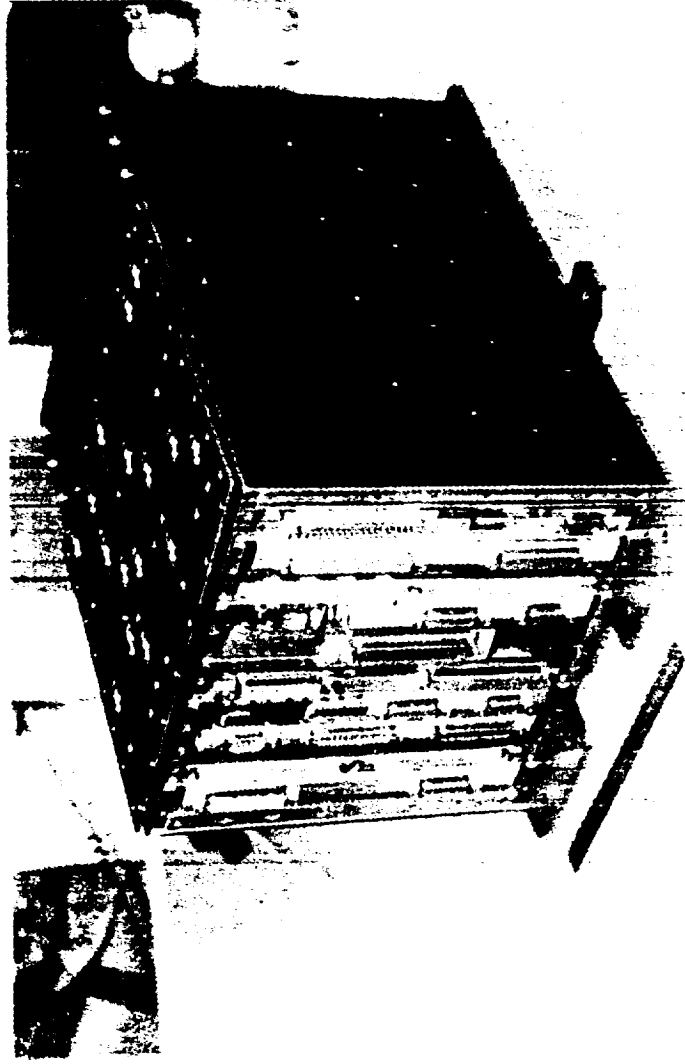
Data Storage for SLAM

Power Conversion for

- LEISA



GEM Physical Dimensions



6 Electronics Boards

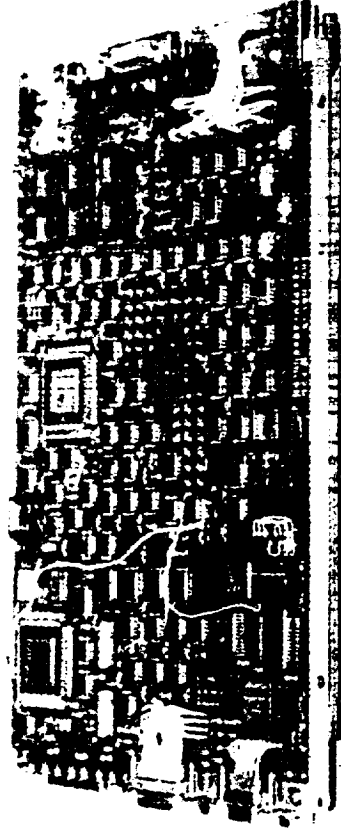
- LVPC
- ESN 1 & 2
- DRAM
- ASCE
- LEISA

8.5" x 13.5" x 7.9"

20 pounds

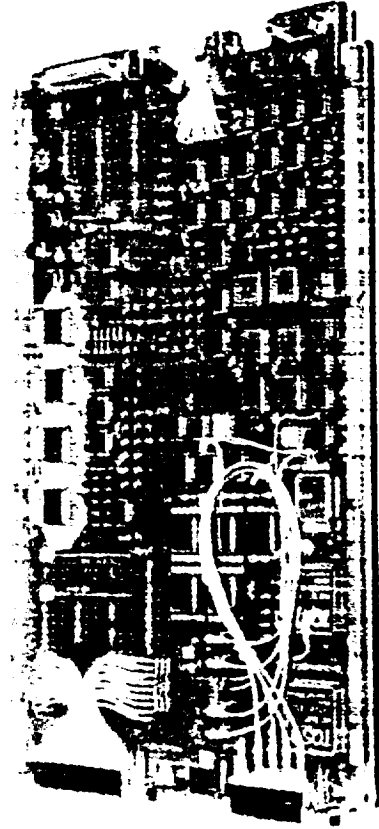


GEM ESN Capabilities



GEM ESN 1

GEM ESN 1



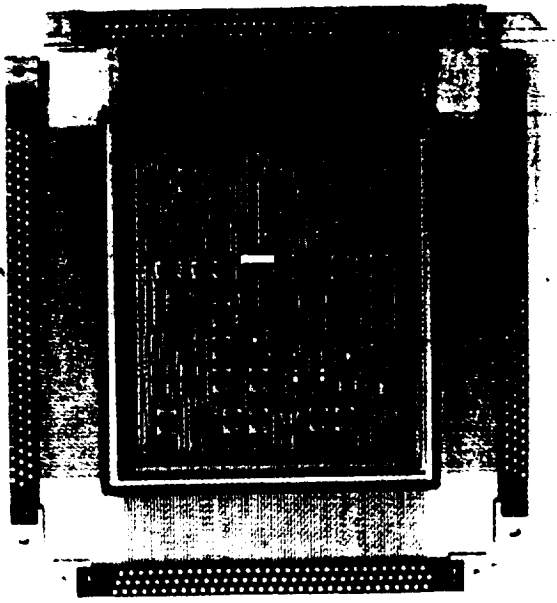
GEM ESN 2

GEM ESN 2

- Harris RTX-2010 Processor
- 160 kbyte EEPROM
- 96 kbyte SRAM
- Gazelle Hot-Rod
- UTM C BCRIM
- 31 Analog Channel
- 2 UARTs

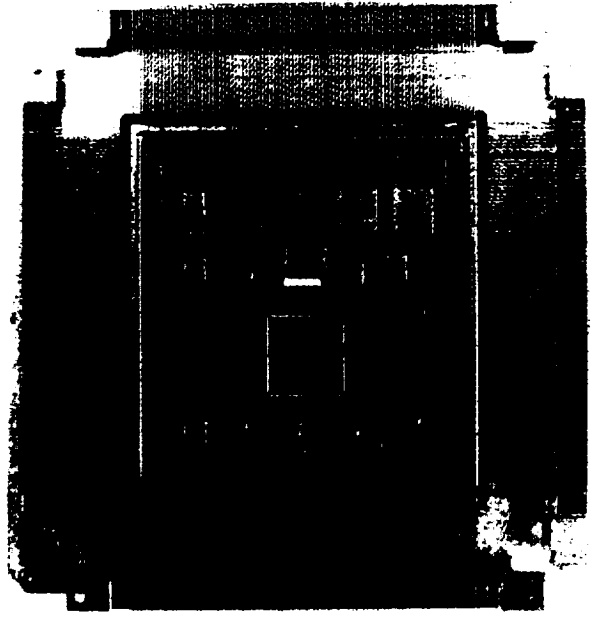


ESN Lessons Learned



- Adding ESN-2 for GPS-2 added
> 2.5 lbs and \$120K

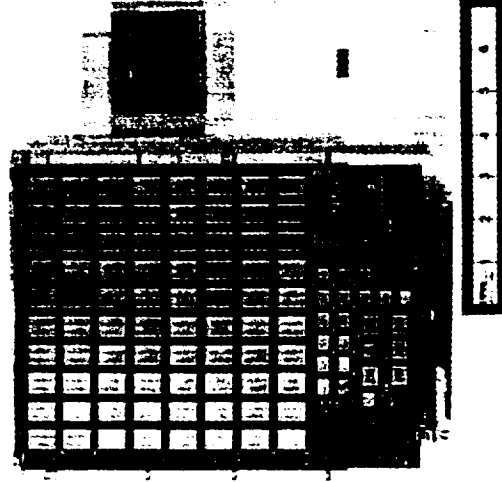
- OSAT parallel effort resulted in
2.5" x 2.5" MCM with the same
capabilities



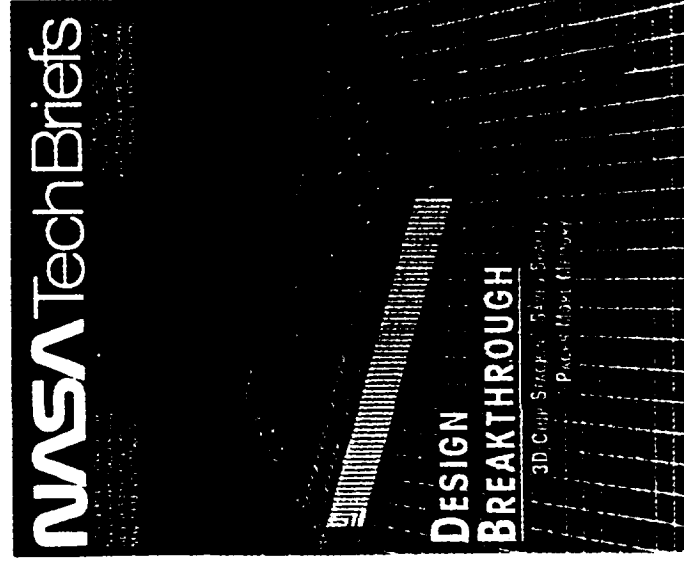
- Available from Honeywell fall '96
at an approximate cost of \$25K



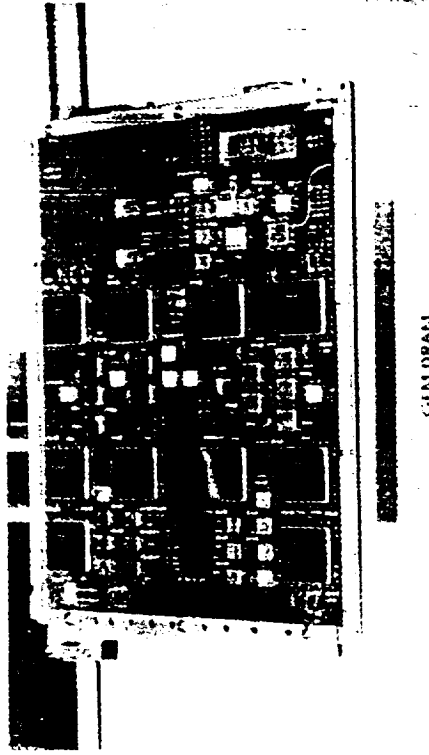
GEM DRAM



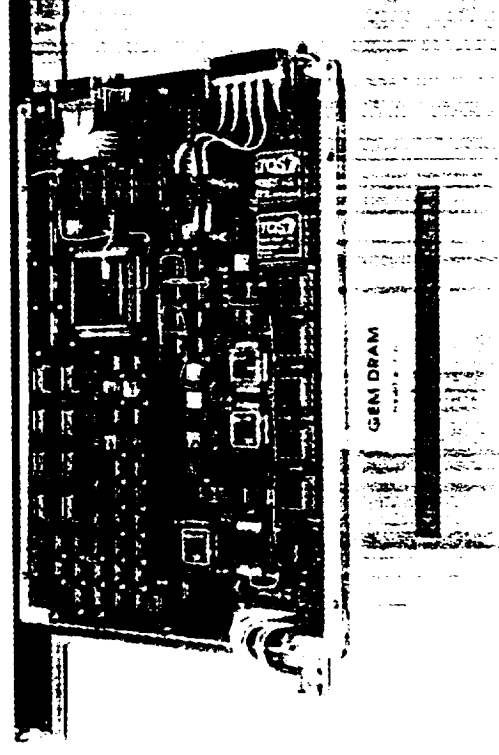
- SBIR with Irvine Sensors to develop DRAM stacking techniques
- 2 stacks/package LCC developed
- 5 die tall (160 Mbit) stacks in GEM
- 10 die tall (320 Mbit) in HST SSR for 2nd Servicing Mission



GEM DRAM



- Provides 200Mbytes (1.6 Gbit) of storage for packetized SLAM data
- Shadowed DRAM with Modified Hamming Code EDAC



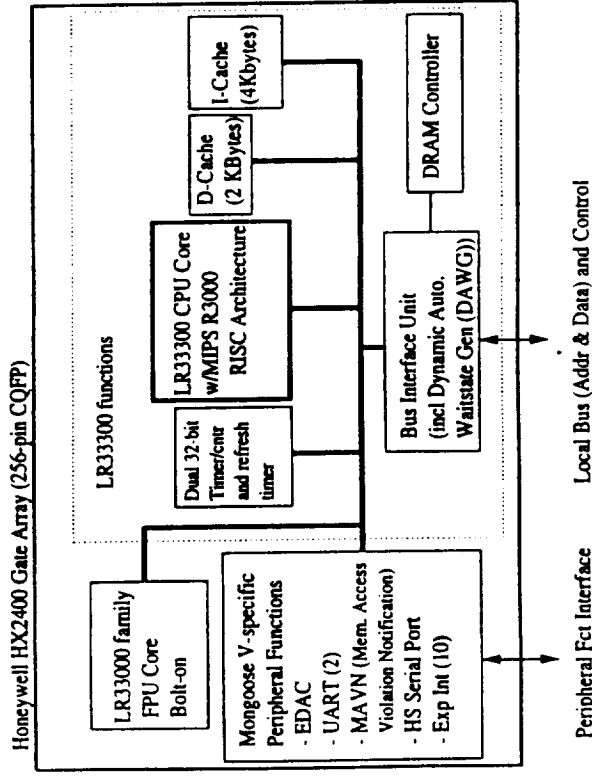
- Rad-Hard R3000 Mongoose I processor
- 256 kbytes EEPROM
- 256 kbytes SRAM
- 200 Mbytes DRAM



DRAM Lessons Learned

- Mongoose I architecture required expensive SRAMs for I-cache and D-cache
- DRAM controller and EDAC were custom designed Actels that drove the development schedule
- OSAT parallel effort resulted in Mongoose V with internal cache, EDAC and DRAM controller on Honeywell HX2400 SOI gate array
- Available from Synova fall '96 at an approximate cost of \$15K-\$25K

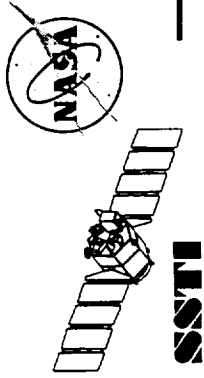
MONGOOSE V CHIP CONFIGURATION



GEM Lessons Learned

- Replacing backplane with internal harness saved approx \$50K
- Periodic informal reviews are necessary to ensure that design meets requirements
- Short and simple ICDs should be written and signed up front and modified as necessary
- Eliminating breadboards and engineering models "straight-to-flight" saves 6-9 months of schedule
- Flight spares of any processor board should be built to allow software development to continue while hardware is being tested and reworked





August 9 – Day 2 – Session 6
Advanced Instrument Technologies



8:00 - 11:45 – E2 Auditorium – Chair: Jay Pearlman

	<u>Speaker</u>	<u>Time</u>
• Hyperspectral Imager	Jay Marmo	8:00-9:00
• Pulse Tube Cryocooler	Manny Tward	9:00-9:45
• Linear Etalon Imaging Spectral Array	Don Jennings/ Dennis Reuter	9:45-10:30
• Optical Pointing Assembly	Marty Beck	10:30-11:00
• Ultraviolet Cosmic Background Spectrometer	Stuart Bowyer	11:00-11:45

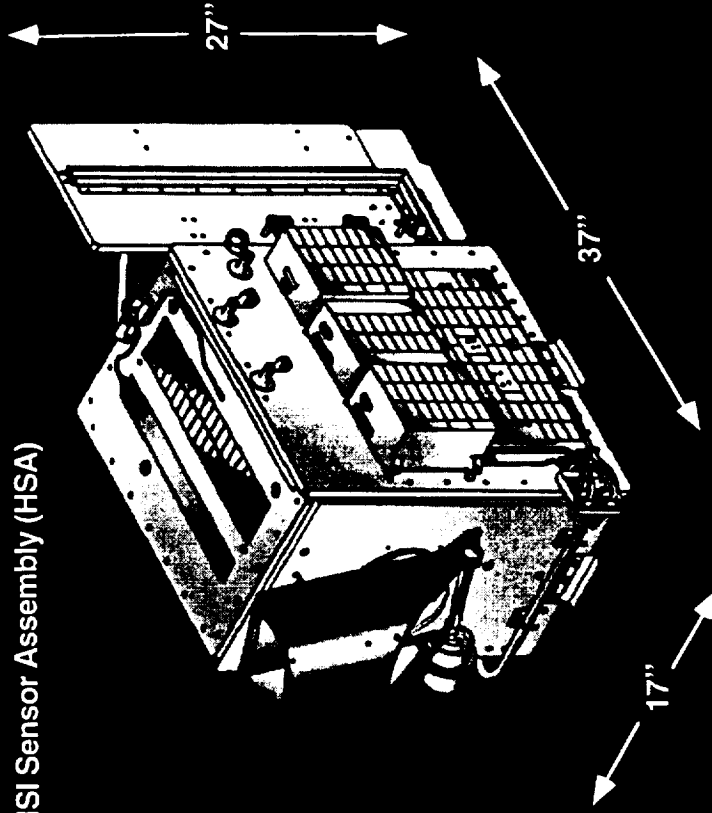
Hyperspectral Imaging Payload For The NASA Small Satellite Technology Initiative Program



9600563.001 OIA 030

Hyperspectral Imager Overview

HSI Sensor Assembly (HSA)



- **Imaging Spectrometer and Panchromatic Camera**

- 5 meter Pan allows sharpening of 30 meter Hyperspectral (HS) images

- **Compact design**

- 34 kg, 52 Watts orbit average

- **High quality HS data**

- 12 bit quantization
- 6% radiometric accuracy
- internal and solar calibration sources

- **High Data Rate**

- up to 450 MBps

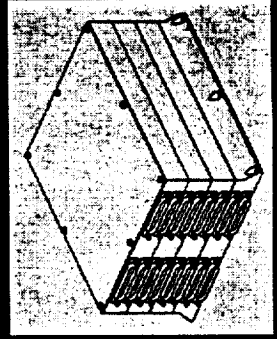
- **Band Selection and Data Formatting**

- any combination of 384 bands

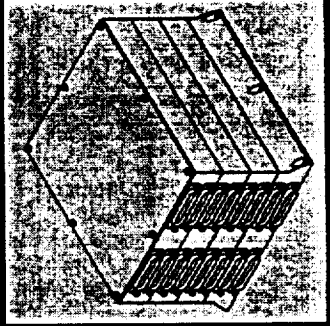
- **Global Access**

- 7 day revisit, +/- 22 degree pointing

HSI Power Electronics (HPE)



HSI Control Electronics (HCE)



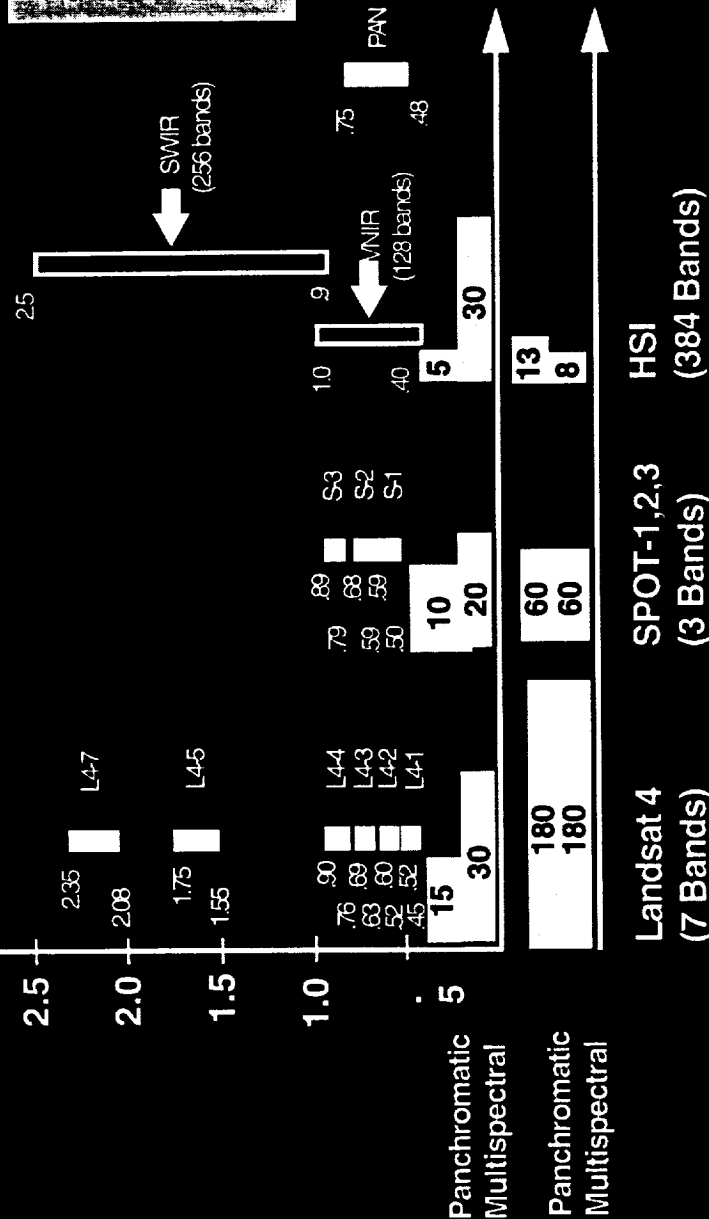
HSI Comparison With Current Space Sensors

Wavelength (μm)

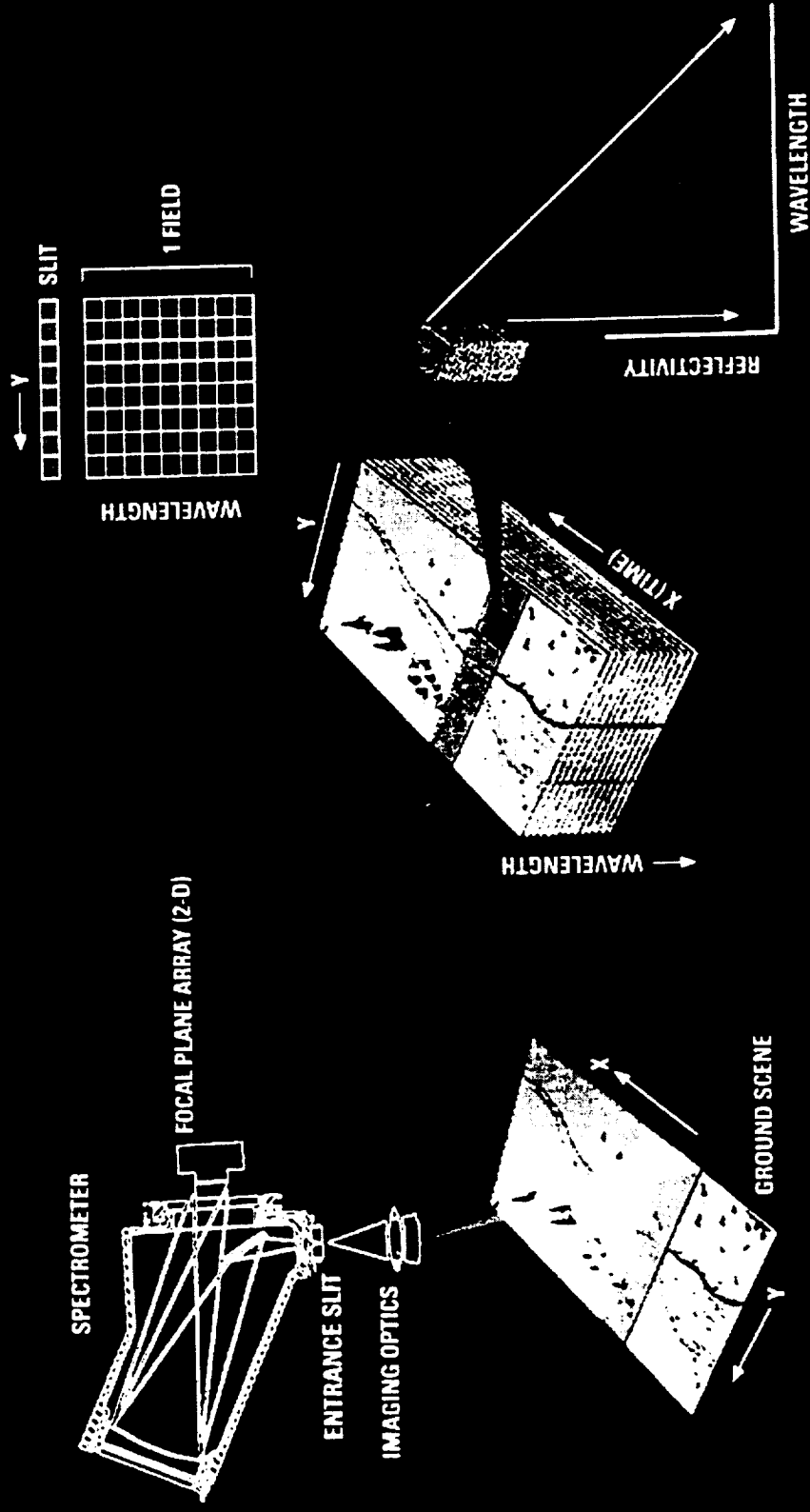
HSI offers 10x better spectral bandwidth,
continuous bands plus 5 meter pan

Applications

- Detection
- Discrimination
- Phenomenology
- Radiometric Calibration
- Sensor Emulation
- Education

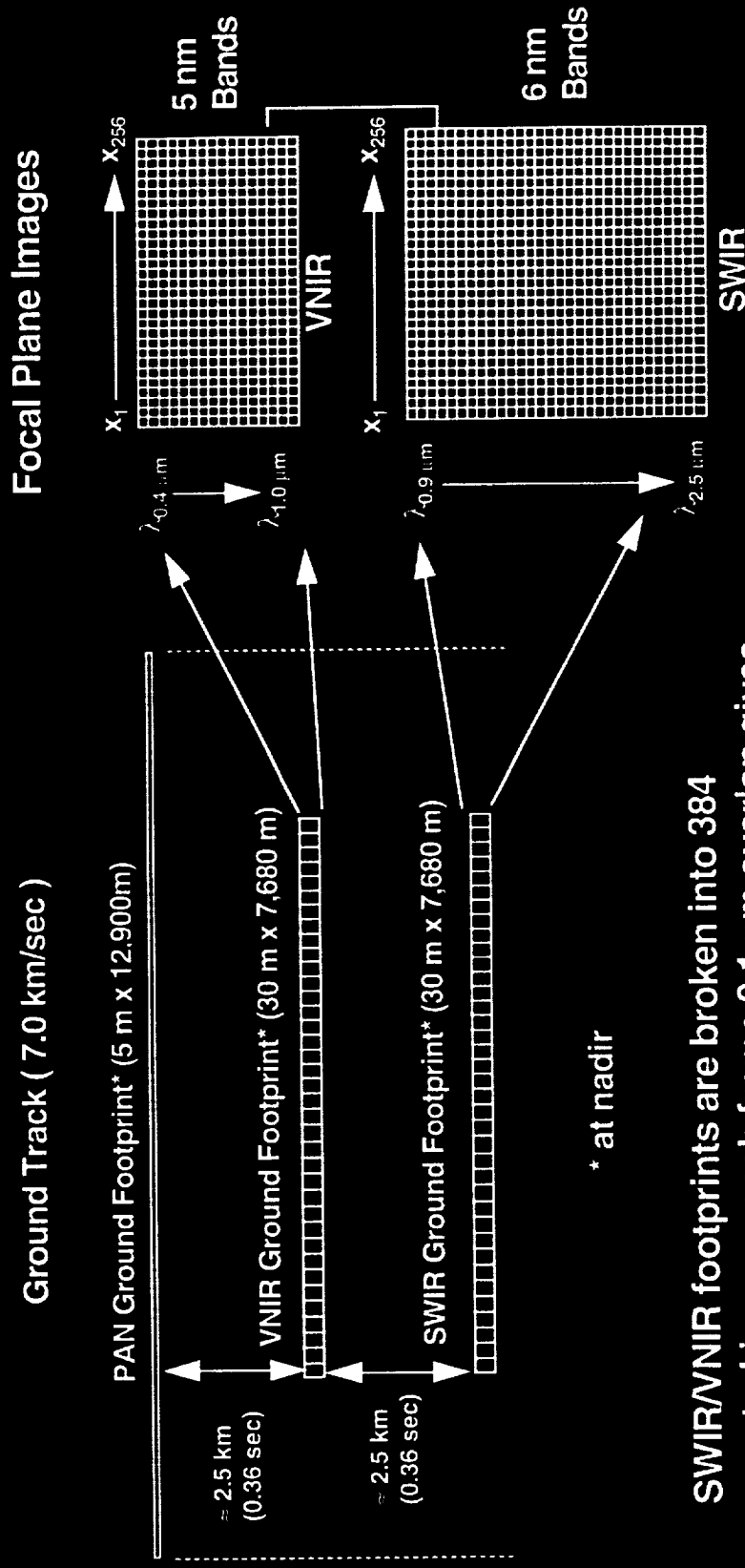


Hyperspectral Imaging Overview



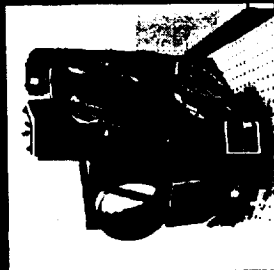
- Spectra of every scene element collected
- Powerful detection discrimination comes from exploitation of detailed spectral signatures

HSI Pushbroom Scan Geometry

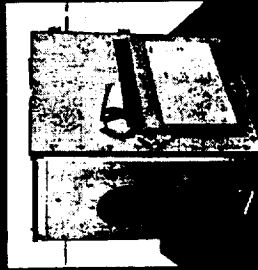


SWIR/VNIR footprints are broken into 384 spectral images each frame 0.1 μm overlap gives constant alignment/cal check

HSI Incorporates Advanced Sensor Technologies

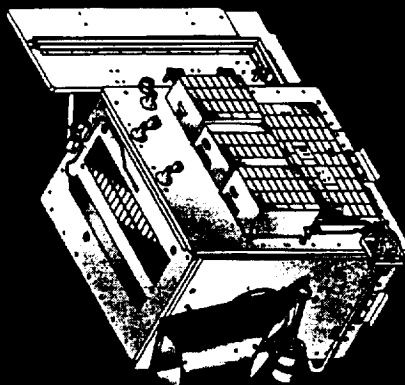


Optomechanical Subsystem
Compact, reflective design
Common fore optics
Aluminum construction



Housing Assembly
Lightweight accessible
OMS isolation, thermal control

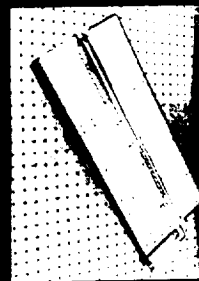
HSI Sensor Assembly



In-flight Calibration Subsystem
Lamps
Solar
VNIR / SWIR overlap



Pulse Tube Cryocooler
Enabling technology



Cryocooler Radiator
Heatpipe & panel
Lightweight, compact



Panchromatic FPA
Repackaged cots CCD
2962 x 1, 2 ports, 1440Hz

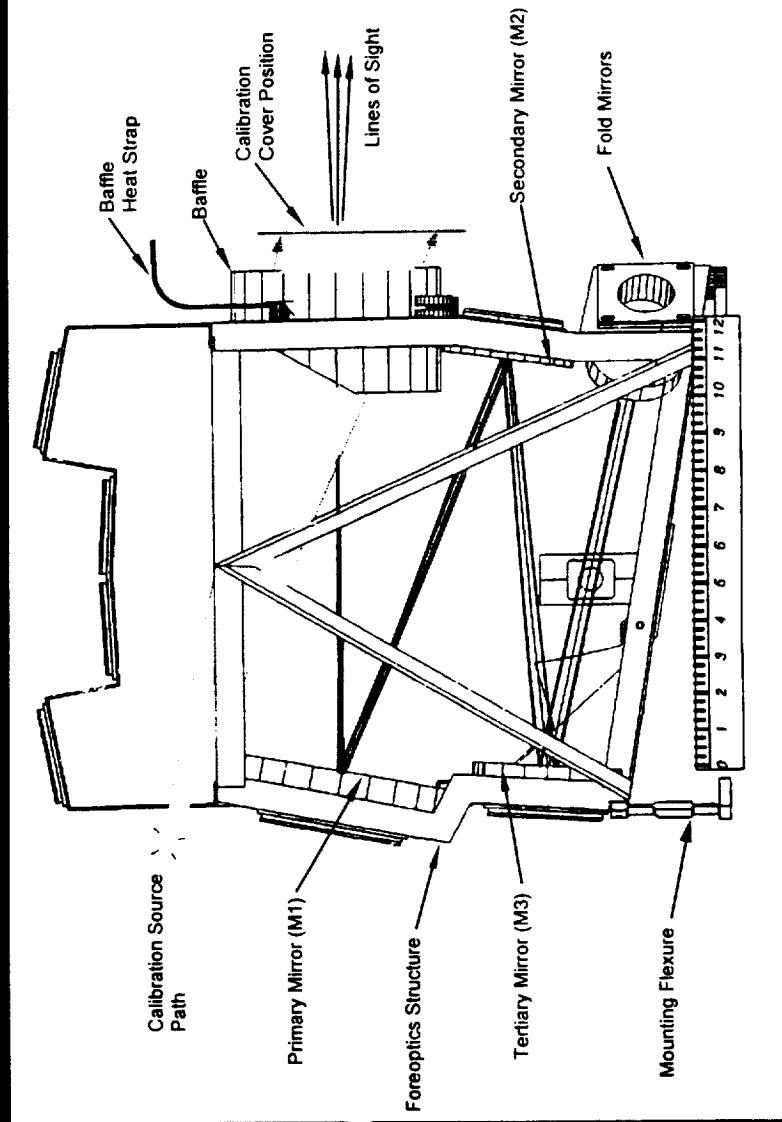
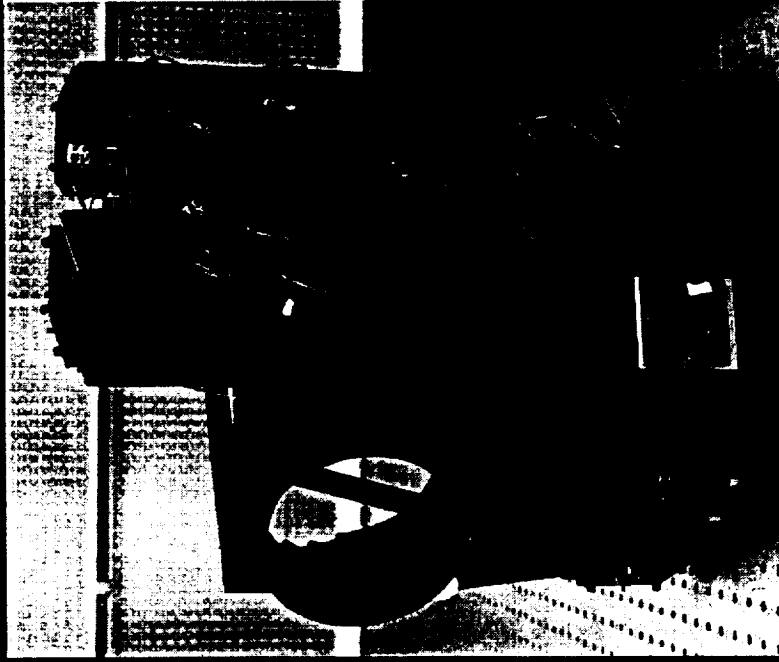


VNIR FPA
Custom CCD
256 x 128, 4 ports, 240Hz



SWIR FPA
Custom HCT hybrid
256 x 256, 4 ports, 240Hz
 $T_0 = 115k$

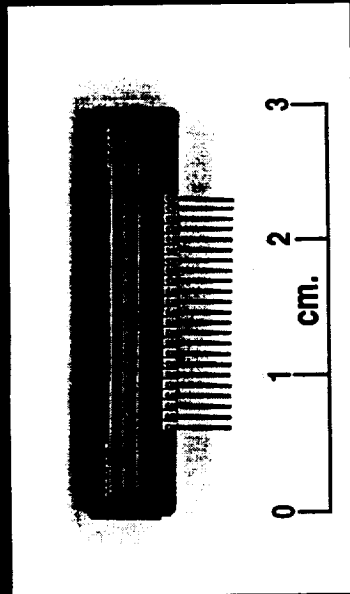
Opto-Mechanical Subsystem (OMS), Foreoptics Design



Foreoptics Telescope, f/8

- Lightweight, all aluminum optics/optical bench design

Panchromatic Focal Plane Module (PAN FPM)

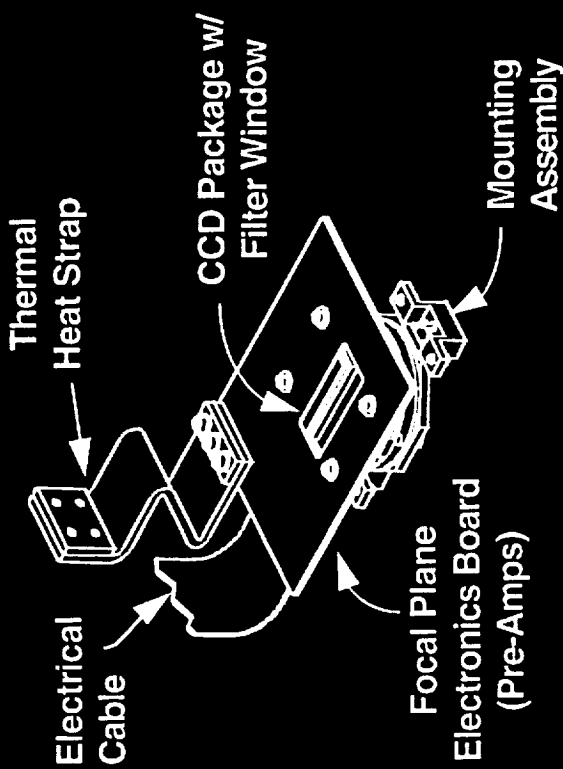


Repackaged Loral CCD-181

Panchromatic FPM Features

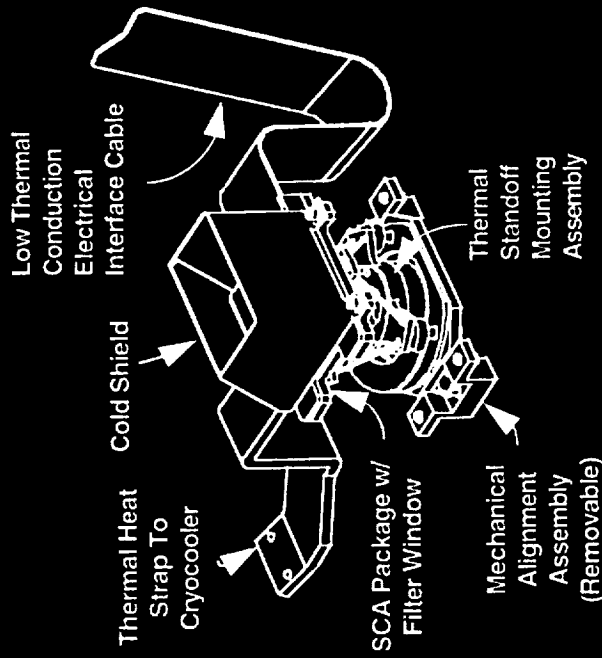
Loral CCD-181

- Off the shelf charge coupled device
- 2592 pixels in linear array
- 10 micron pixel pitch
- 2 output channels
- 2 MHz data rate
- 8 bit ADC



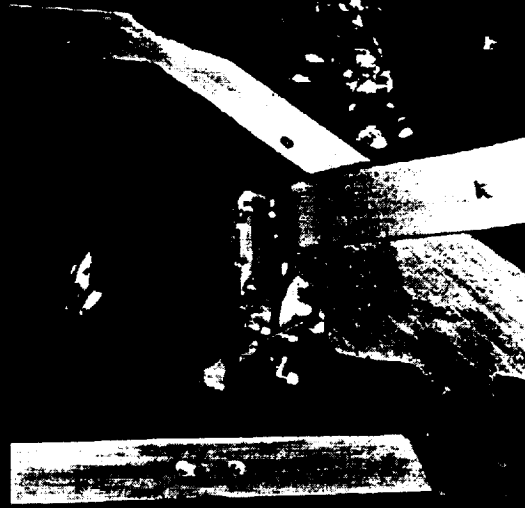
Panchromatic FPM Assembly

Shortwave Infrared Focal Plane Module

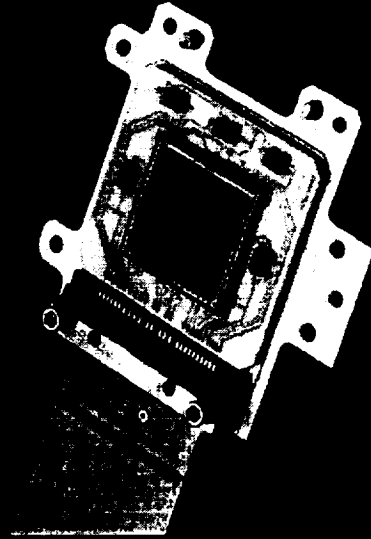


SWIR FPM Features

- Area MCT Array, 256x256 Pixels
- 60x60 micron pixels
- 115 Kelvin Operating Temperature
- 240 Hertz Frame Rate
- 4 MHz Pixel Rate Per Port
- On Chip Pre-Amps

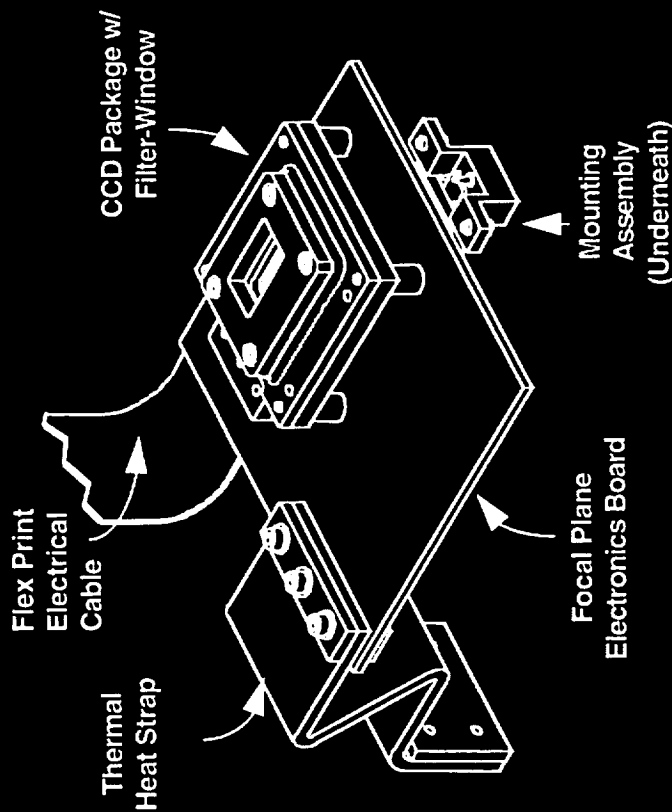


SWIR FPM mounted in spectrometer



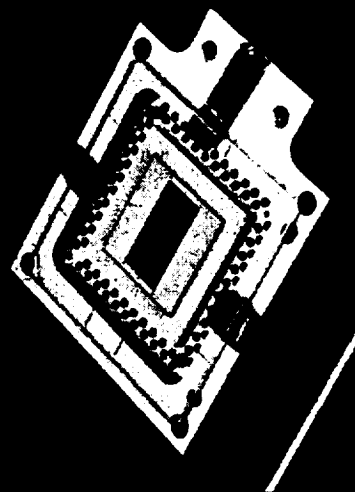
Hybird SCA mounted on package

Visible/Near Infrared Focal Plane Module (VNIR FPM)



VNIR FPM Features

- Area CCD Array, 256x128 Pixels
- 60x60 micron pixels
- Zero Celsius Operating Temperature
- 240 Hertz Frame Rate
- 2.4 MHz Pixel Rate Per Port
- Pre-Amps, High Speed Drivers Adjacent To CCD

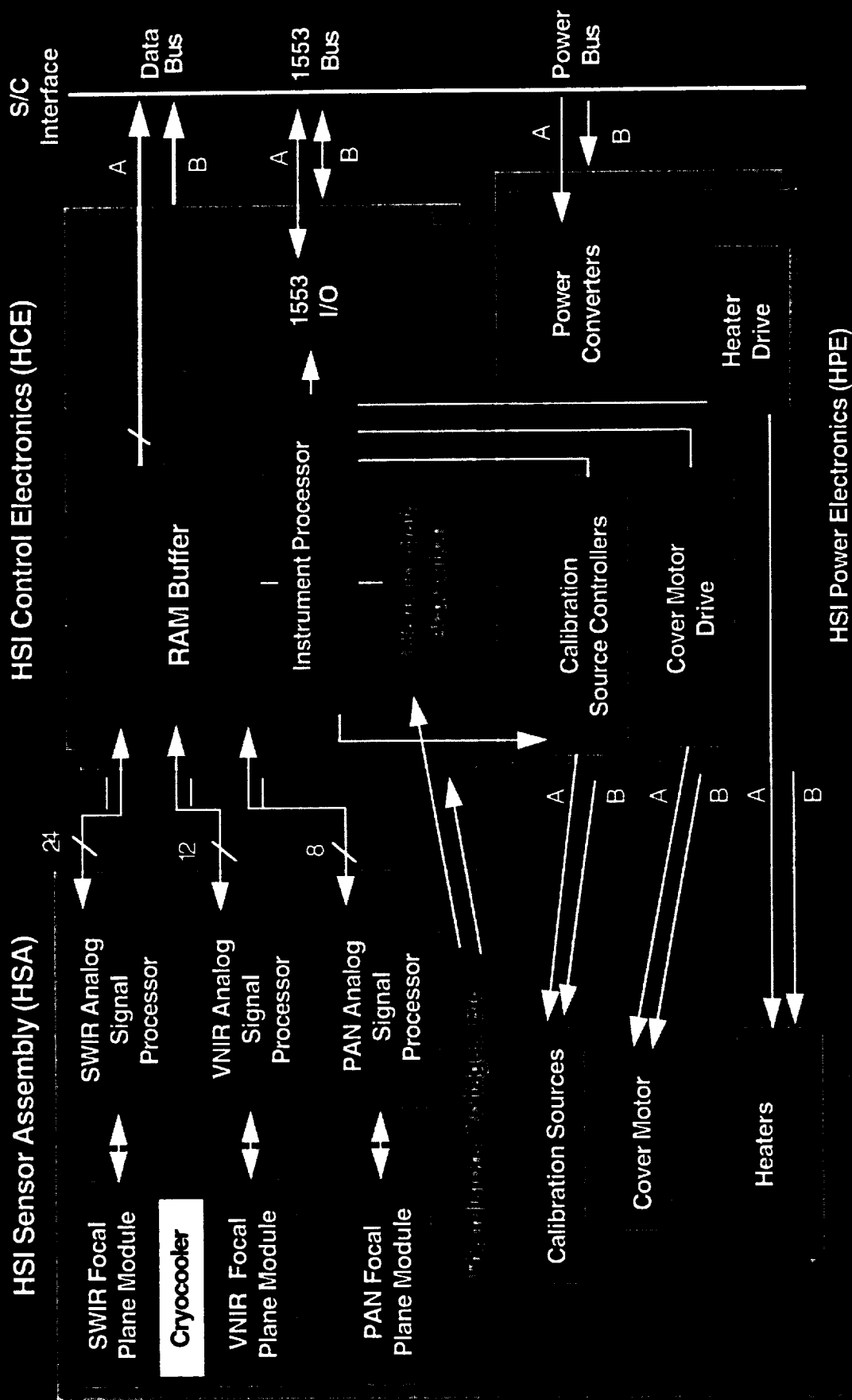


CCD mounted in package

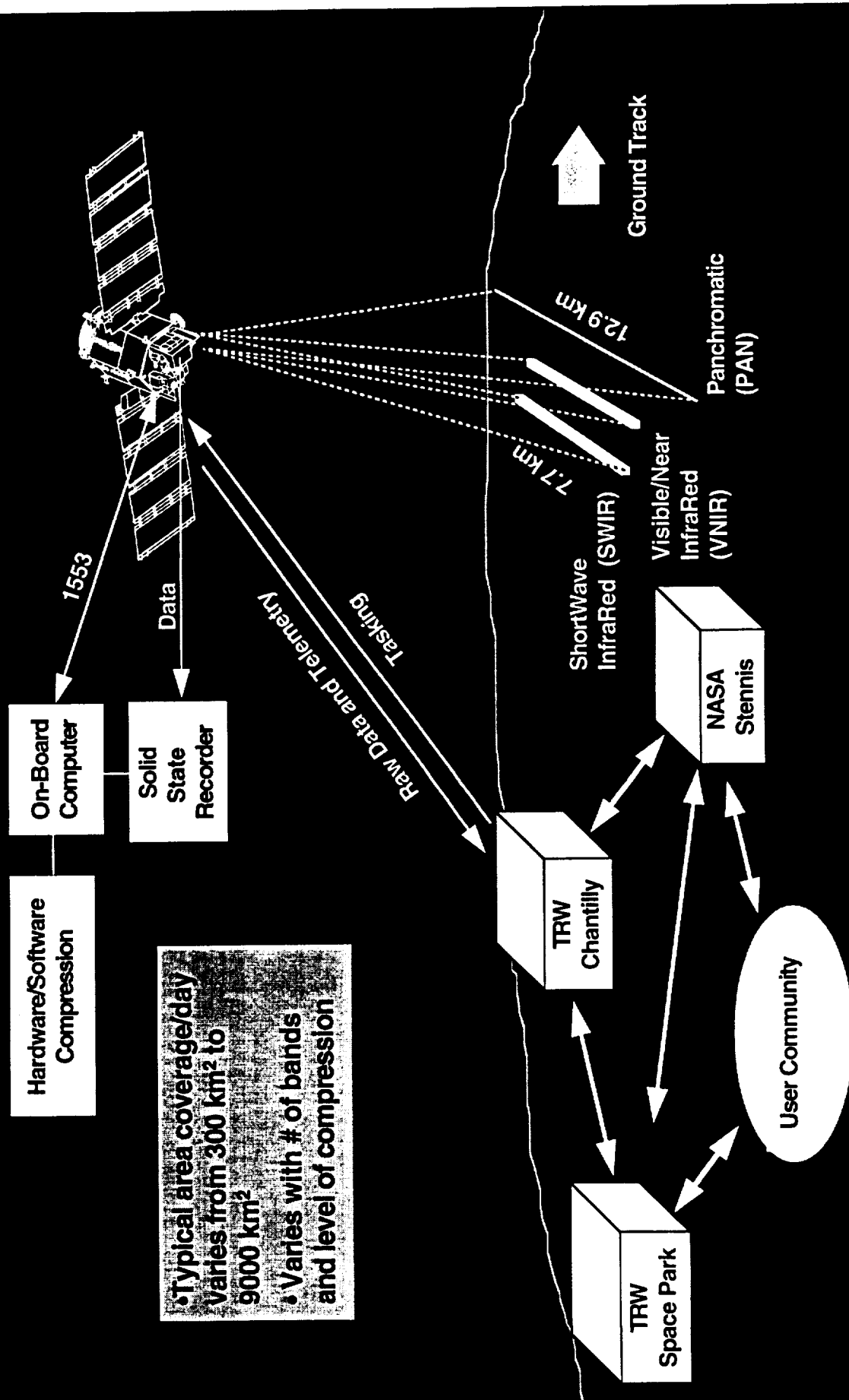


VNIR FPM mounted in spectrometer

HSI Electronics Architecture



HSL Concept of Operations





SSTI LEWIS MINIATURE PULSE TUBE CRYOCOOLERS

E. Tward

Cryocoolers



- Long life (>10 yrs), space cryocoolers are in production
- Reliability, efficiency and producibility make **pulse tube cryocoolers** the technology of choice
- Technology and coolers have been scaled over two orders of magnitude in cooling power
- Two miniature pulse tube coolers have been in life test since Jan. 1994
- TRW's first two miniature pulse tube coolers cooling two ir payloads, HSI (HyperSpectral Imager) and LEISA (Linear Etalon Imaging Spectrometer Array), will fly on TRW's SSTI smallsat (LEWIS) in Nov 1996
- Two miniature flight pulse tube coolers for AF project nearing completion
- Six miniature flight pulse tube coolers are being built for another AF project
- One larger capacity PT cooler is being built for flight for MTI. Delivered in 97
- A larger capacity redundant flight cooler system is being completed for NASA AIRS/EOS system. Delivery early 97
- TRW's miniature Stirling cooler first flight (delivered 94) is in early 97 on the HTSSE 2 payload cooling a TRW high temperature superconducting (HTS) device

Pulse Tube Cryocoolers

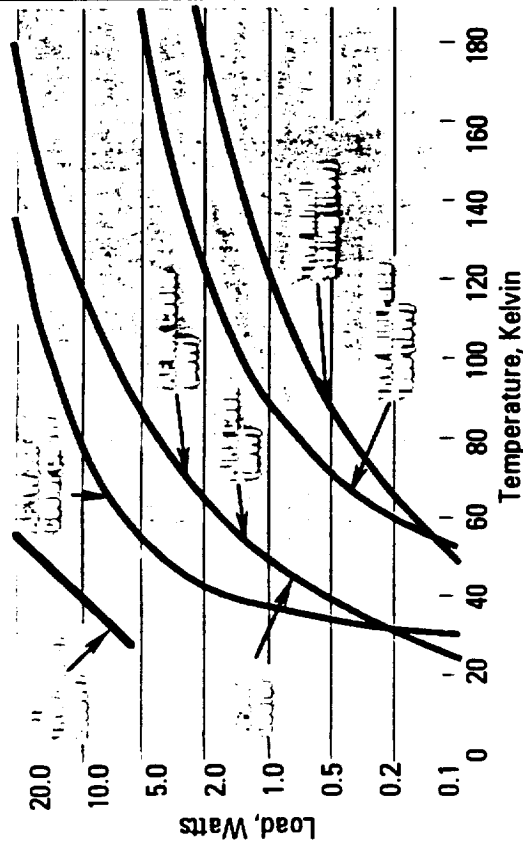
Capability



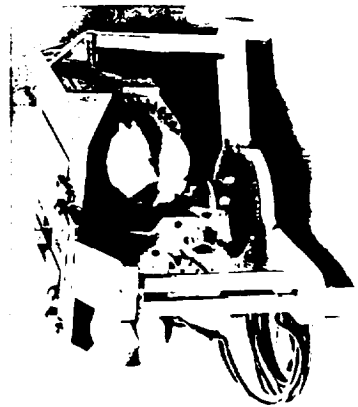
- **Power**
 - Efficiency comparable to Stirling coolers - the gold standard
- **Cooling Power**
 - Scaleable from milliwatts to kilowatts
- **Cooling Temperature**
 - $< 10\text{K}$ demonstrated
- **Vibration**
 - Dynamically balanced to very low levels ($< 0.1\text{N}$, 0 to 1 kHz)
- **Acoustic Noise**
 - Compressors are barely audible
- **EMI**
 - Typical of 30 to 60 Hz linear motor
- **Reliability**
 - Space design is typically 10 year with 98% confidence

TRW Cryocooler Capability

Wide Performance Capability



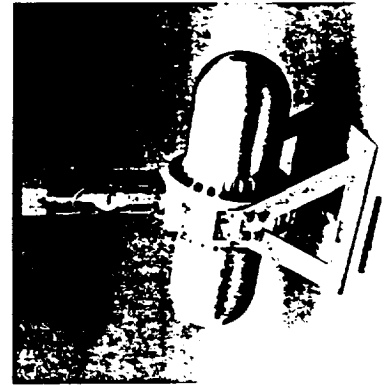
Large Pulse Tube Coolers



• AIRS



• MTI



• 35 K

Miniature Coolers -

Only supplier of small flight coolers



Miniature Stirling Cooler

- HTSSE 2 - 1997 flight



Miniature Pulse Tube Cooler

- SSTI-LEISA - 1996 flight
- SSTI-HSI - 1996 flight

272676-94-3

275183-96-5

272262-94-3

A. INTRODUCTION

RATED POWER
COOLER

B. SPECIFICATIONS

1.000

1.000

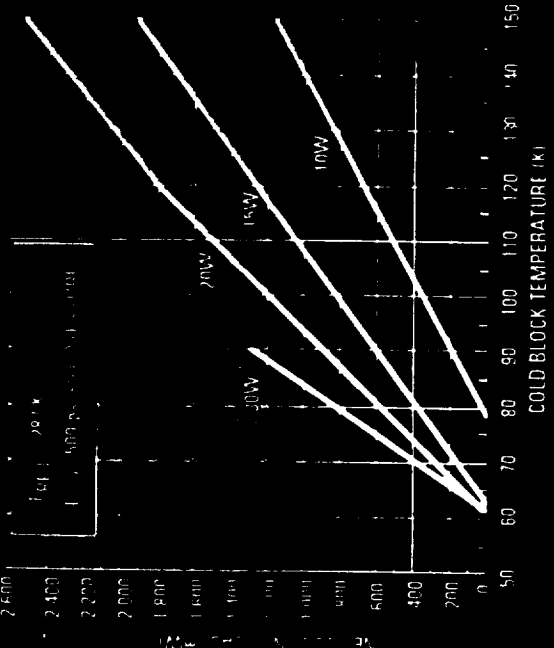
1.000

RATED POWER
COOLER
ELECTRONICS

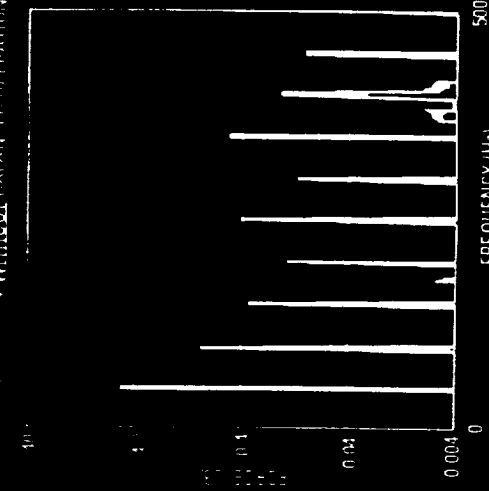
FOOTPRINT
COOLER
ELECTRONICS

C. MEASURED COOLER PERFORMANCE

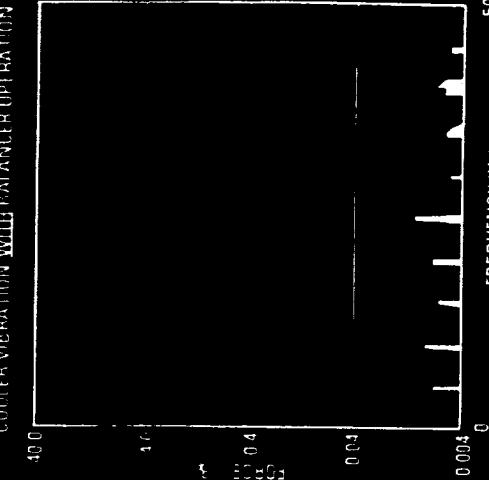
LOAD LINE VS. INPUT POWER



COOLER OPERATION WITHOUT BALANCE OPERATION



COOLER OPERATION WITH BALANCE OPERATION



COLD BLOCK TEMPERATURE (K)

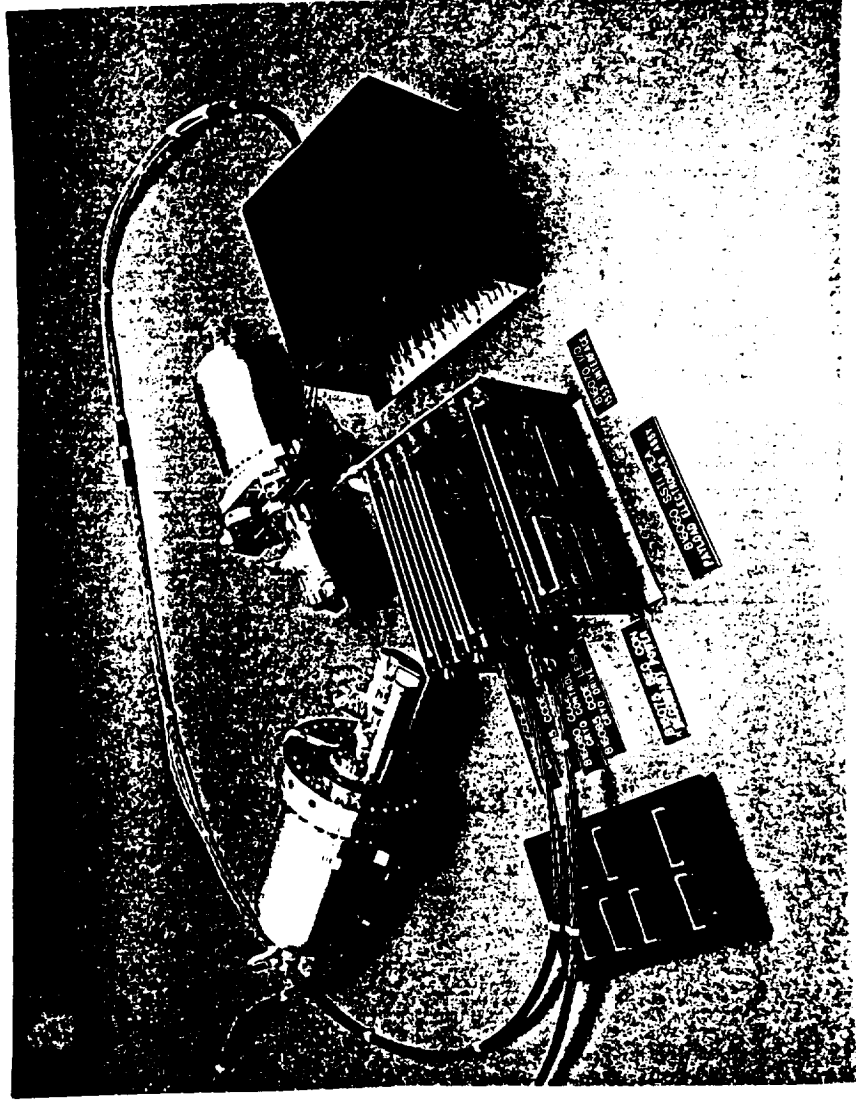
FREQUENCY (Hz)

COOLER

SSTI LEWIS Cryocooler Drive



HSI and LEISA pulse tube cryocooler control electronics are both housed in Payload Electronics Assembly



- Controller provides cooler power with
 - temperature control
 - self induced vibration control
 - autonomous operation
- Each cooler controller incorporates
 - a digital control board
 - a motor driver board
 - telemetry interface

Summary



- Space qualified pulse tube cryocoolers are now in production
- Reliability and producibility and reproducibility make pulse tube cryocoolers the technology of choice for space
- Technology and coolers have been scaled over 2 orders of magnitude in cooling power
- Cooling has been demonstrated to less than 10K

LEISA

LINEAR ETALON IMAGING SPECTRAL ARRAY (LEISA)

LEISA: 1.0 to 2.5 μm IR SPECTRAL CAMERA

Donald E. Jennings and Dennis C. Reuter

TRW: SSTI-Lewis Technology Utilization Workshop
8 - 9 August, 1996
Redondo Beach, CA

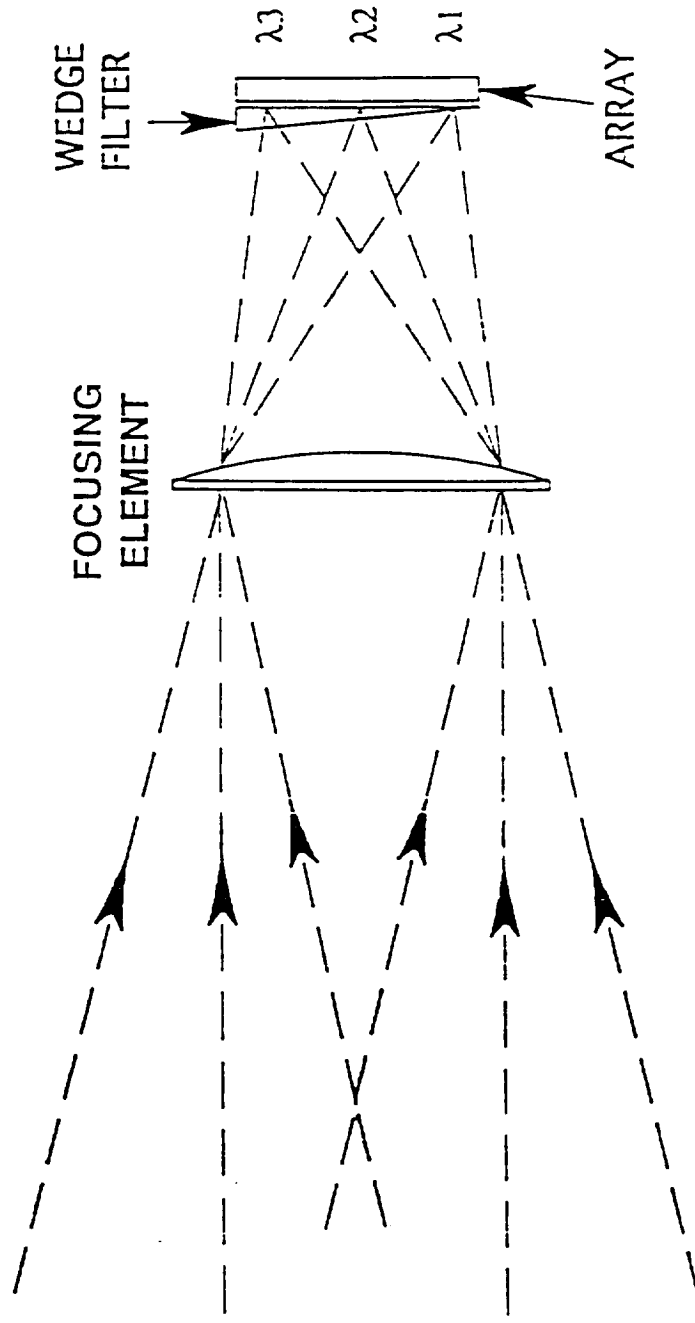
GSFC

<i>LEISA</i>	GENERAL OVERVIEW • Linear Variable Etalon (LVE) Spectral Filter Directly Over 256 x 256 NICMOS 3 IR Array. Wavelength Logarithmic Function of Position. • 2-D Spectral Imager. Single Frame is 2-D Spatial, 1-D Spectral. Mapping Done in Push-Broom Mode by Spacecraft Orbital Motion. • Reduced Complexity, Mass, Cost Compared to Conventional Imagers. • Spectral Coverage: 1.0 - 2.5 μm (256 Channels) Spectral Resolving Power ($\lambda/\Delta\lambda$): 250 (Constant) • Pixel Field-of-View (IFOV): 300 m Array Field-of-View (FOV): 77 km • LEISA Complementary to HSI in Infrared. Spatial Resolution Ten Times Lower; Image Size Ten Times Greater. Steerable FOV (OPA) Calibrate Using Diffuse Solar Scatterer, Moon and HSI
GSFC	

LEISA

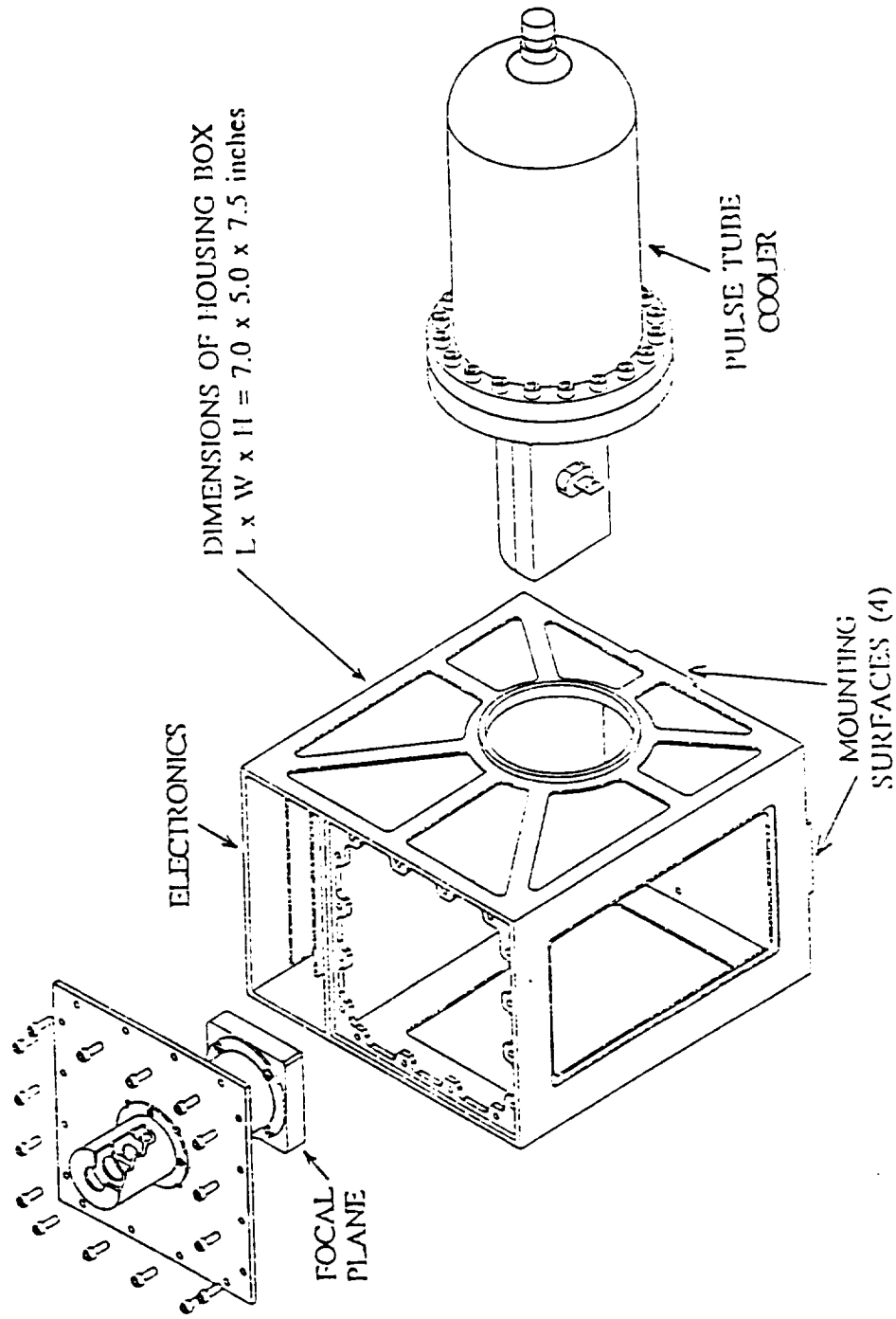
WEDGED FILTER CAMERA (LEISA) OPTICS SCHEMATIC

WEDGED FILTER SPECTRAL IMAGER



GSFC

MECHANICAL CONFIGURATION



<i>LEISA</i>	SCIENCE OBJECTIVES
• Map Reflectance Spectra of Surface and Atmospheric Features. • Clouds: Particle Phase, Size, Coverage, Height, Cirrus Detection. • Vegetation: Coverage, Type, Health (Liquid Water Estimation), Residue. • Aerosols: Composition, Particle Size. • Volcanoes and Forest Fires: Extent, Smoke, Temperature. • Ocean and Fresh Water: Industrial Effluent, Oil Spills. • Snow Fields: Extent, Grain Size, Age. • Aurora and Airglow: Non-LTE Excitation, Chemistry (Tracer for O₃). • Urban Studies.	
GSFC	

LEISA

FULL ASSEMBLY SUMMARY

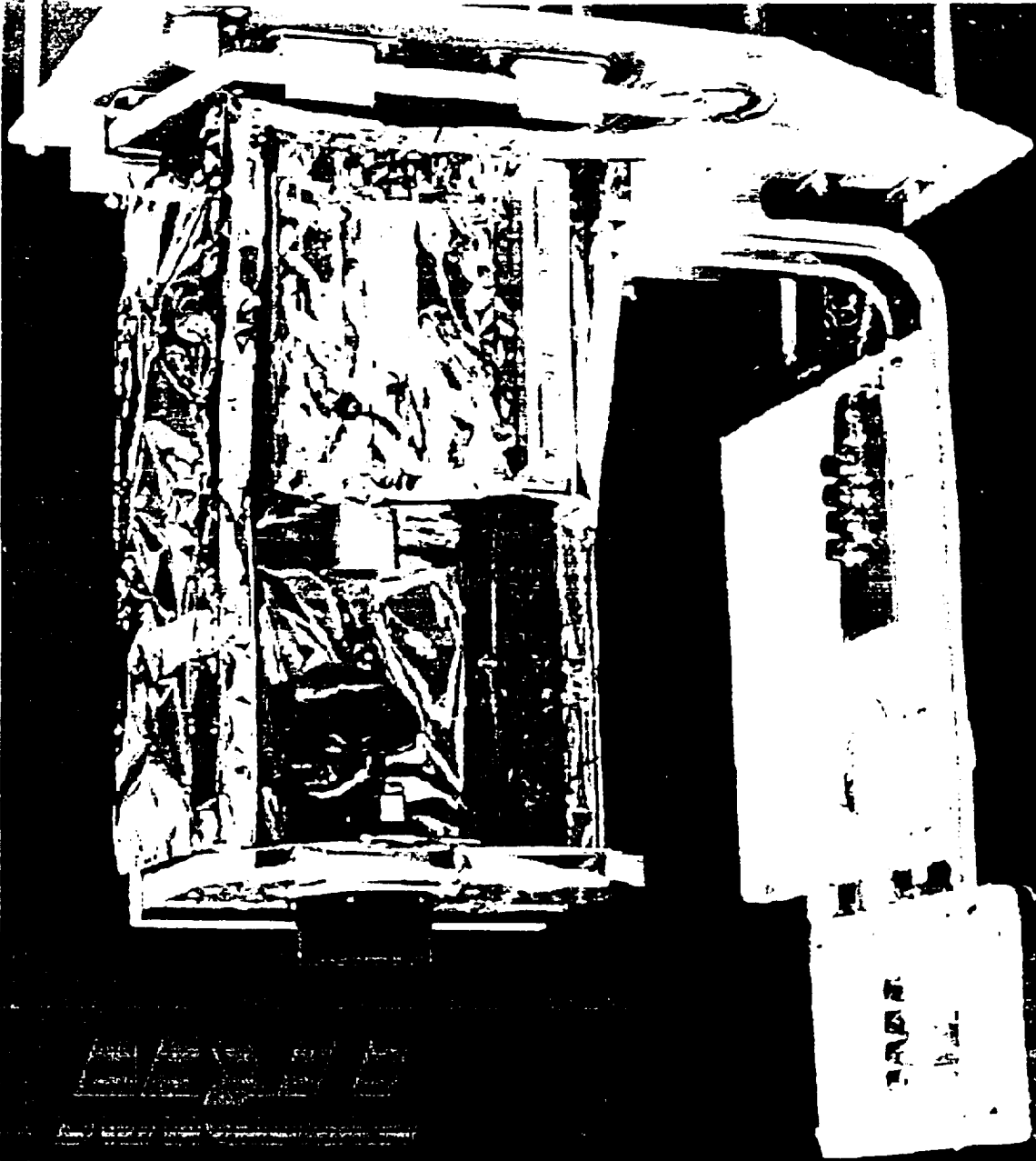
MODULE	MASS (kg)	POWER (W) ¹
Optics Module	2.5	7
GEM Board	0.5	1.8
OPA	0.8	6
Cooler	2	22
Mounting Structure	2.1	N/A
Radiator Panels	<u>1.2</u>	<u>-----</u> 2
TOTAL	9.1	36.8

1 This is the power while data is being taken. At other times the optics module, GEM board, and OPA may be turned off (0 W). The pulse tube cooler runs continuously.

2 The radiator panels are equipped with heaters for temperature control.

GSFC

LEISA COMPLETED ASSEMBLY - 3/28/96

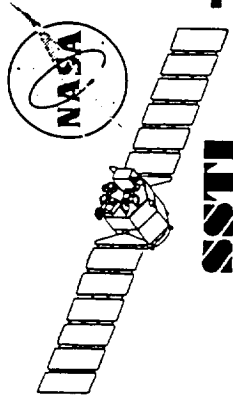


LEISA COMPLETED ASSEMBLY - 3/28/96

LEISA COMPLETED ASSEMBLY - 3/28/96

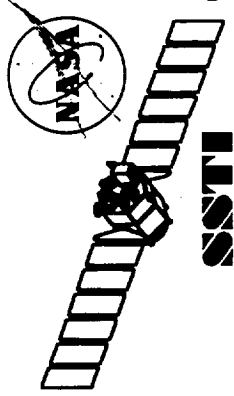
LESSONS LEARNED

- Possible to Develop Instrument from Concept to Delivery in Fewer Than 18 Months.
- Minimize Formal Meetings; Maximize Informal Group Interaction.
- Industry/Government Partnership Works: TRW Supplied Pulse Tube Cooler, OPA, Bracket; Required Close Cooperation for Success.
- Parallel Development to Maximum Extent Possible; Maintain Flexibility
- Government Procurement Process Can be Rate Limiting Step.



Optical Pointing Assembly

Martin Beck
August 9, 1996

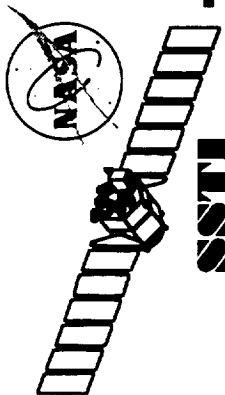


Optical Pointing Assembly Top Level Requirements



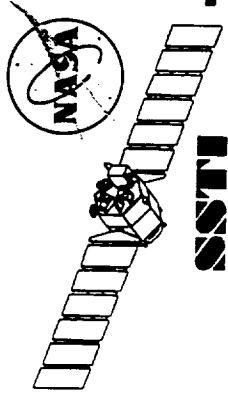
-
- Existing Unit, Developed On BP/AITP, To Be Refurbished For SSTI
 - Payload Support Function For LEISA Instrument
 - Provide Wide, Agile Field Of Regard (FOR) For LEISA
 - Extends LEISA FOR To:
 - +/- 15° Elevation (Spacecraft Pitch)
 - +/- 60° Azimuth (Spacecraft Roll)
 - Allows FOR To Be Changed Within 40 mS Over Wide Range
 - Minimum Step Size 33.5 microradians
 - Maximum Step Size 7.8°
 - Provide High Position Resolution & Accuracy
 - Position Resolution 12 microradians
 - Position Accuracy/Knowledge < 150 microradians

Optical Pointing Assembly Configuration

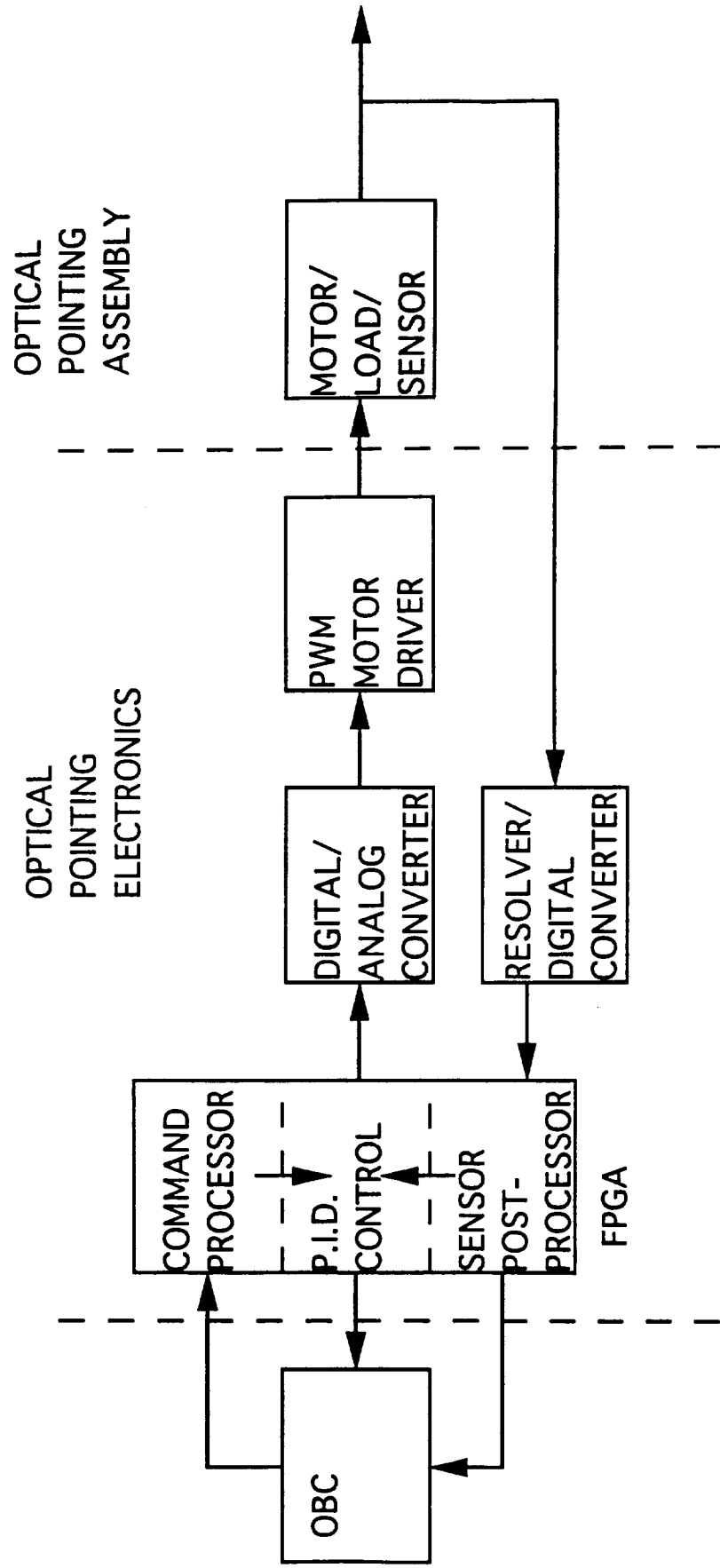


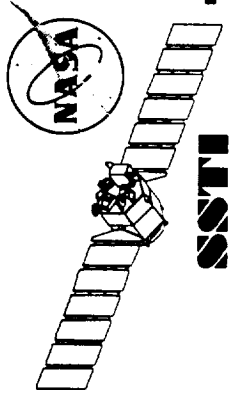
TRW





Optical Pointing Assembly Physical Block Diagram

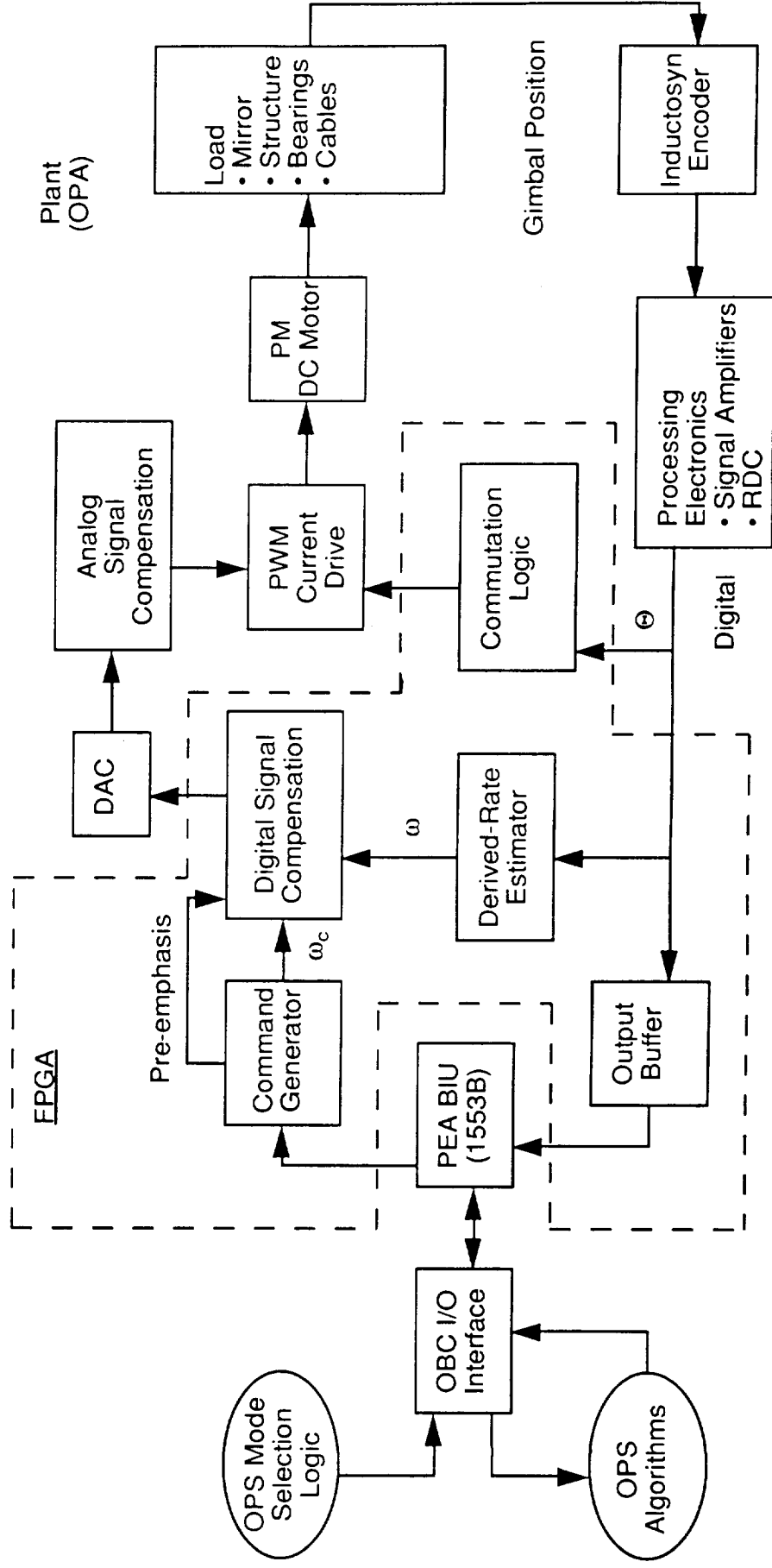


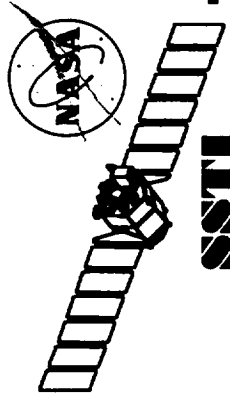


Optical Pointing Assembly Functional Block Diagram



OPS Az/EI Drive Electronics



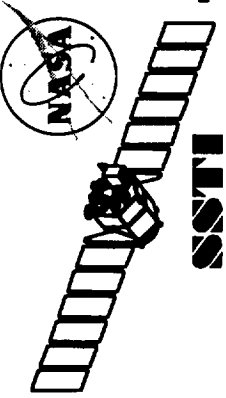


Optical Pointing Assembly Requirements Vs. Capabilities



Existing Design

<u>Parameter</u>	<u>Source</u>	<u>Requirement</u>	<u>Capability</u>	<u>Comments</u>
Mirror Total Travel	AITP			To Be Tested
Elevation	"	15°	20°	x2 for FOR
Azimuth	"	120°	174°	Hardstops
Step Size, Max.	"			To Be Tested
Elevation	"	3.75°	3.9°	
Azimuth	"	7.75°	7.8°	
Step & Settle Time	"	<40 mS	Complies	
Position Resolution	"	12 microradians	Complies	To Be Tested
Position Accuracy	"	<150 microradians	Complies	To Be Tested
Weight	"	< 0.82 Kg	0.8 Kg	Measured
Power	"	< 6 W	5.4 W ave.	Calculated



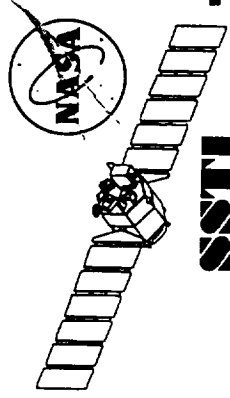
Optical Pointing Assembly Requirements Vs. Capabilities



(Continued)

Existing Design

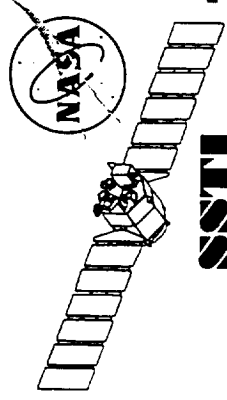
<u>Parameter</u>	<u>Source</u>	<u>Requirement</u>	<u>Capability</u>	<u>Comments</u>
Optical Design:	AITP			
Mirror Size	"	9.3cm x 5.9cm	10.2cm x 6.8cm	Measured
Substrate	"	Be	Be, I-250	Elliptical
Surface Figure (633nm)	"	<0.25 wave	0.3wave, p-v flat	Measured
Surface Roughness	"	<30 Angstroms	0.1wave, rms irreg.	"
Coating Reflectance:			<30 Angstroms rms	"
Visible	"	>75%		IR-97
SWIR	"	>97%		Measured
1-2.5 microns	SSTI	TBS	TBD	"
				To Be Measured



Optical Pointing Assembly Description



- **Motors - Direct Drive, Brushless DC**
 - Azimuth Axis: 2 Phase Commutated, 8 Pole Pairs
 - Elevation: Homopolar (No Commutation)
- **Motor Drive - PWM (40 KHz) From PEA**
- **Position Sensors - Inductosyn (Elevation - Segmented)**
 - 2.8125° Cycles
 - 12 Microradians Resolution
 - 30 KHz Carrier
- **Position Index**
 - Azimuth: Mid-Scan Hall Sensor
 - Elevation: Mechanical Stop (OBC-Initialized At Turn-On)



Optical Pointing Assembly Description (Continued)



- Improvement in performance over its predecessors by 4
 - Steps 7.5° and settles to 18 bits of resolution in .040 sec.
 - internal gains of 20,000
- Novel approach minimize size and power
 - FPGA based control electronics design minimizes size
 - » all gains are binary and shift registers are used to multiply
 - » no micro-processor
 - elevation motor only 10% efficient
- MCM H-Bridge drives motor windings
 - well behaved at 0 current
- 4" X 6" PC Board provides power and control

The Diffuse EUV Spectrometer "UCB"

Jerry Edelstein and Stuart Bowyer

to appear in

EUV, X-Ray and Gamma Ray Instrumentation for Astronomy VII
SPIE vol. 2808 O. Siegmund, ed., 1996.

The diffuse EUV spectrometer "UCB"

Jerry Edelstein and Stuart Bowyer

Space Sciences Laboratory, University of California,
Berkeley, CA 94720-7450

ABSTRACT

An extreme ultra-violet diffuse spectrograph known as the Ultraviolet Cosmic Background spectrometer is scheduled for a 1996 launch on the NASA SSTI mission *Lewis*. UCB is one of three prime science instruments aboard the *Lewis* spacecraft and is scheduled to conduct observations for 3 to 5 years. The spectrograph will obtain spectra of diffuse 550 to 1100 Å radiation with a sensitivity improvement of an order of magnitude or more in comparison with previous work. UCB incorporates new technology such as a special diffraction grating, an anti-coincidence guarded micro-channel plate detector system, low-radioactivity ultra low-noise micro-channel plates, and a chemical treatment for enhancing detector efficiency. The observations will contribute important new information about the Galaxy's local interstellar medium and about speculative scenarios regarding exotic nuclear particles in dark matter. We describe the instrumentation and the UCB science mission.

Keywords: Diffuse EUV spectrometer, low-noise micro-channel plate detector, space-flight instrumentation, EUV optics.

1. INTRODUCTION

The EUV diffuse background (100 to 1000 Å) is the most poorly known of any of the diffuse astronomical backgrounds. A wide variety of sources have been proposed to radiate in this bandpass. One source which is certainly producing flux in this band is the hot interstellar medium that pervades our Galaxy. The actual lines observed from a hot ISM will be strongly dependent upon the temperature and thermal history of this material¹. The detection of just a few emission lines from this source will add tremendously to our knowledge of this poorly understood material. A second source mechanism which is known to radiate in this band is the inflowing interstellar medium which is resonantly excited by solar radiation². A third, speculative possible contributor to the cosmic EUV background is emission from neutrinos in our Galaxy undergoing radiative decay³. Another source of EUV line emission is atmospheric airglow²⁴. The study of airglow emission will elucidate processes occurring in the upper atmosphere and magnetosphere.

Only upper limits to diffuse EUV background flux exist. These upper limits are one to two orders of magnitude larger than expected sources of cosmic flux. Initial investigations of the diffuse EUV astronomical background were carried out with broad-band detectors on rockets and short duration orbital flights^{4, 5, 6}. More recent efforts which have provided broad band upper limits to the cosmic EUV flux include the *Alexis* Satellite⁷ and the *EUVE* Satellite⁸. A number of spectroscopic measurements have provided weak upper limits with crude resolution of ~ 30 Å⁹ and ~ 15 Å¹⁰. More recent spectroscopic observations have yielded astronomically interesting limits, such as *EUVE*¹¹ and a sounding rocket instrument¹². Marginal detections of 1035 Å background have been claimed using *HUT*¹³ while the *DXS* instrument¹⁴ has yielded tentative, yet confusing detections.

2. THE UCB INSTRUMENT

We have developed a novel, compact instrument known as the Ultraviolet Cosmic Background spectrometer (hereafter referred to as UCB) to measure the diffuse EUV background with unprecedented sensitivity. Our instrument performance goals are a bandpass coverage from 600 to 1050 Å with ≤ 5 Å spectral resolution; 3σ sensitivity to diffuse line emission of no more than 2000 photons/sec/cm²/sr (or line units, LU), with a goal of 200 LU after 100 hours of observations; and simultaneous field imaging with ≤ 5 arcmin resolution. We studied a number of possible designs and established several new methods and techniques to achieve these goals, including a unique fast optical

design optimized for diffuse spectroscopy; an extremely low-noise Micro-Channel Plate (MCP) photon detector and an anti-coincidence system.

The UCB instrument is one of the three prime payloads aboard the *Lewis* mission, a NASA SSTI (Small Spacecraft Technology Initiative) satellite produced by TRW. A primary goal of the SSTI program is to develop advanced technologies for small spacecraft design and methodology to greatly reduce the cost of space missions using a fast-track schedule and a minimum of oversight. The all-composite 850 lb. spacecraft is scheduled for launch on the Lockheed-Martin LMLV in late 1996. The mission operational lifetime is 3 years with a 5 year goal. *Lewis* is three-axis stabilized with 15 arcsecond knowledge. The UCB $8.4^\circ \times 25.6^\circ$ field of view will be oriented toward the anti-sun direction and scan the entire ecliptic plane every 12 months. Periodic calibration and special inertial target pointings will be conducted. Observations will be integrated over long periods, from 100 to 1000 hours, depending on the science objectives.

2.1. OPTICAL DESIGN

We have designed a new grating spectrometer specially optimized for diffuse radiation by examining potential combinations of grating surface and ruling parameters. We developed a general expression describing the optical path for mono-chromatic radiation incident upon an arbitrary polynomial surface, using variable space diffraction rulings, and then converging to a single point on the detector. We chose plane-cylindrical radiation emanating from a slit aperture as a source because it well describes a diffuse radiation field. The optical concept is schematically shown in Fig. 1. In contrast, a spherical radiation source emanating from a point on a slit better describes the illumination from an object at infinity focussed by a collecting optic. Following Fermat's Principle, we minimized the variation of the path function over the grating's aperture and found solutions which eliminated aberrations to fourth order for on-axis illumination. Constant line spacing and rotationally symmetric grating surfaces were then imposed on our solution to simplify the ruling and figuring process. An elliptical surface of rotation, a readily manufacturable and testable optic, was found to provide a solution with corrections to the third order.

We established a number of design requirements in order to achieve a sensitive EUV imaging spectrograph that would fit a compact volume suitable for small space-missions: use of a single, reflective optic for maximum throughput; a fast optical system ($\leq f/4$); a 15–20 cm focal length; an optics size of ≤ 10 cm; and an active detector size of ≤ 2.5 cm. We chose to restrict our design to normal-incidence optics for low cost and for the small envelope of a folded optical path. The design constraints were combined with our elliptical substrate solution to construct a candidate design which was then numerically ray-traced over a range of illumination angles and wavelengths to verify the optical performance. We examined and optimized the performance as a function of f-number, slit height and detector location. In Table 1, we summarize the key optical parameters of the design. We found that our design performed well and retained at least 75% of its resolution performance to 4° off axis. Moreover, spatial resolution better than 0.1° was achieved along the sky in the direction along the spectrograph slit, which permits radiation from bright stars to be identified and removed.

Our new optics scheme yields a single-optic imaging spectrograph that is very well suited for diffuse observations. The design, while using a simple optical figure and ruling, is fully correctable to third-order regardless of optical speed. A tall slit, and consequently large collecting area, can be used because the design is based upon cylindrical-source illumination. Large imaging fields, and consequently large grasp, can be achieved because focusing radiation in the off-axis direction requires less curvature in comparison to point-source illumination optical schemes. In contrast to our design, conventional single-optic Rowland spectrographs¹⁵ designed for point-source illumination, and even its toroidal derivatives¹⁵ provide poor imaging at moderate off plane angles. The conventional single-optic Wadsworth design¹⁵ provides good imaging for point sources but has limited solid angle due to spectral resolution constraints placed upon its in-plane angle of acceptance. (Single-optic Wadsworth designs also require a mechanical collimator.) The single-optic, toroidal Rowland-Wadsworth hybrid of Cotton, et al.¹⁶ is similar to our design, but is not exactly and specifically corrected for cylindrical-source illumination and is expected to show larger aberrations than our fully corrected design for very fast optical systems such as the $f/2.2$ UCB.

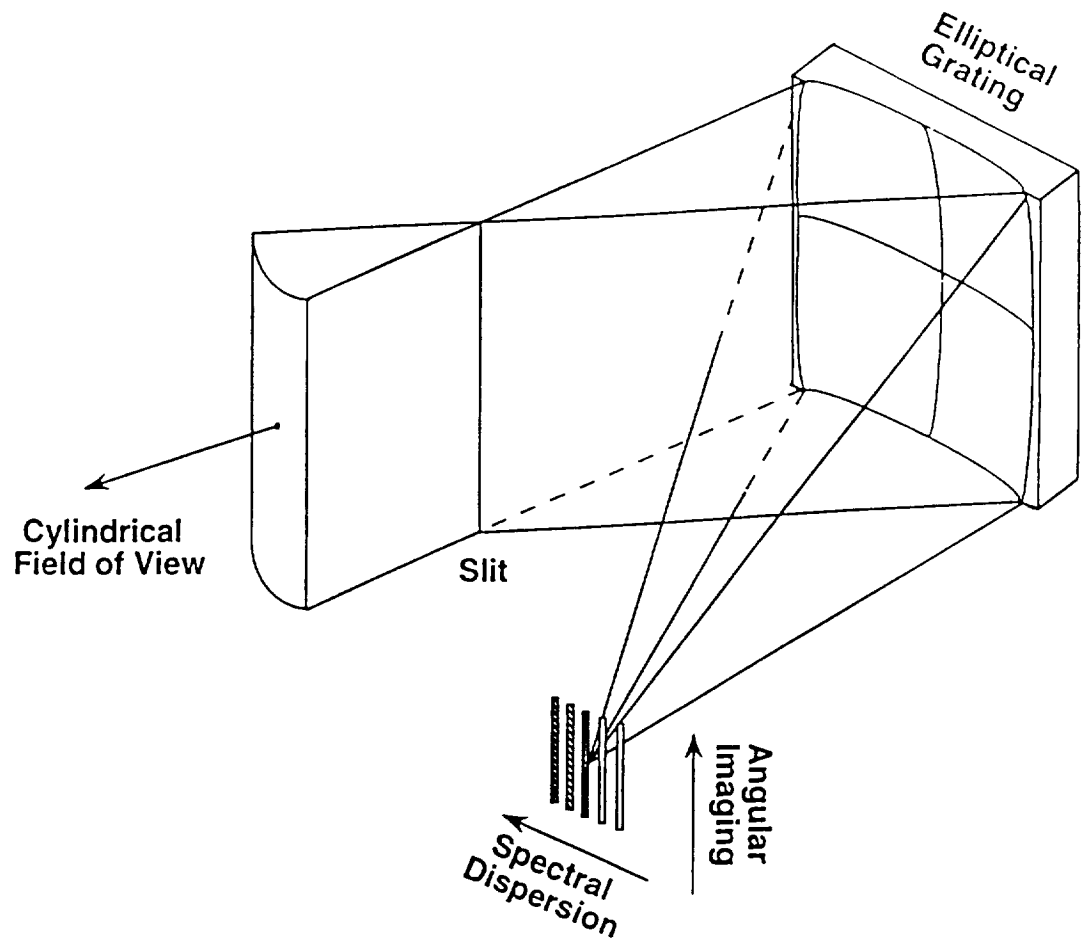


Fig. 1. Schematic diagram of the optical concept of the spectrometer.

2.2. SPECTROGRAPH DESCRIPTION

Our very-low signal sensitivity goals require precise and accurate subtraction of background noise. Consequently, we have incorporated a number of special and unique features in the spectrograph to maximize signal, minimize noise, and allow for accurate counting rate measurements. The completed spectrograph system, entirely fabricated by our group at Space Sciences Lab, U.C. Berkeley, is shown in mechanical layout in Figure 2. Light enters the spectrograph via an entrance baffle, filter wheel and slit assembly and then encounters baffles, the diffraction grating, more baffles, and an open-faced micro-channel plate detector.

Great care has been taken to reject low energy charged particles, abundant at orbital altitudes, which can create a significant background noise source. The entrance baffle assembly uses optical baffles, a permanent magnet and low-voltage electric field to divert extraneous light and charged particles away from the slit entrance to the optics chamber. The slit, baffles and grid near the detector face are polarized at selectable low voltages to further reject ions. Besides the slit and a baffled evacuation port, the optics chamber is hermetically sealed. The chamber can be placed at high vacuum for ground testing or optics storage by using an internal flap-valve and an external pump.

To allow for accurate background characterization and subtraction a rotating filter-wheel mechanism, driven by redundant stepping-motors, gates the 0.15 x 60 mm slit. The slit wheel rotation timing is carefully coordinated with data acquisition to allow for accurate count rate determination. The filter-wheel has four operational positions: 1) Closed, 2) Open, 3) MgF_2 crystal, and 4) 1000 Å thick Aluminum film. Data are taken at all four positions, at selectable time intervals, in order to detect (respectively) 1) detector background noise, 2) low-energy EUV radiation signal, 3) internally scattered 1216 Å airglow radiation noise, 4) high-energy EUV radiation signal.

The diffraction grating substrate, following our elliptical prescription for a cylindrical-source spectrograph, was made of stress-relieved aluminum overcoated with electroless nickel. The diffraction grating was holographically recorded with a special resist technique to eliminate the interference of substrate back-reflection. The grating was coated with silicon carbide by the Optical Thin Film Laboratory at GSFC. The grating was mounted at three points using spherical bearings and a threaded rod system which could be coupled to precision stepping motors for alignment and then locked for flight. The grating adjusters preserved the high-vacuum hermeticity of the optics chamber.

At EUV wavelengths a prime contributor to the noise is background in the detector⁸. This background consists of two components (a) an internal background due to the radioactive decay of potassium in the microchannel plates, and (b) a charged cosmic ray particle background. To reduce internal radioactive noise, a major innovation used on this mission is a lightweight braised ceramic-metal MCP photon counting detector with special low-internal background, low-radioactivity MCP's supplied by Galileo Corp. To reduce the cosmic ray background, the detector is surrounded with a charged particle anticoincidence system. Two photomultiplier tube (PMT) assemblies detect scintillator flashes induced by high-energy particle events and flag photons for rejection. To our knowledge UCB will contain the first space-flight of low-radioactivity MCP's and the first implementation of anti-coincidence rejection to achieve an ultra low-noise MCP detector.

We used a new technique¹⁷ to enhance the MCP detector's sensitivity at EUV wavelengths. The conventional method for sensitivity enhancement in the EUV is to coat the MCP surface with an alkali halide photo-emissive material¹⁸. The performance of these materials is known to degrade upon exposure to moist laboratory air. This imposes costly handling procedures for open faced MCP detectors that cannot afford the weight or complexity of flight-deployable vacuum door mechanisms. We developed and life tested a chemical treatment technique that provided enhanced EUV detective quantum efficiency which is not moisture sensitive. Furthermore, unlike most alkali-halide photo-cathodes used for the EUV, our technique did not significantly increase the quantum efficiency for 1216 Å radiation. This is important because 1216 Å radiation is a potential internal noise source due to grating scattering of geocoronal radiation.

Spectrograph electronics support the detector function: Three high-gain, ultra low-noise charge sensitive amplifiers receive the microchannel plate signals via a wedge and strip encoding anode¹⁹ and provide shaped pulse signals to the downstream analog-to-digital conversion system. These charge amplifiers are especially designed to be free

of overload saturation artifacts from cosmic-ray events. The amplifiers also contain arm/fire circuits to send a large capacitor's low-voltage pulse to the detector for electrostatic ejection of particulate contamination on the anode. An important part of the detector electronics is an electronic pulse calibration system. Each second, a trio of charge pulses is generated by an on-board quartz-crystal controlled oscillator. The amplitudes of these pulses are controlled by a digitally switched attenuator to produce accurate charge signals for the detector electrodes; these charge amplitude ratios have been chosen to encode positions in the extreme corners of the field of view of each detector. In this way, the stability of the entire detector electronics can be monitored through instrument development, calibration, test, integration, and during the mission.

The UCB instrument is operated by way of an Electronics Box contains removable circuit boards restrained with locking rail structural clamps that also serve as thermal dissipation paths to the chassis. An ADC circuit board converts sensor pulses into digital science information. Automatic circuitry exists to prevent sensor damage from 'count-rate overload' due to excessive light or charged particle levels, or from sensor anomaly. The digital flight electronics system is centered in a high capability digital signal processor (DSP) with associated ROM, RAM, control logic, and communications chips. The architecture adopted is based on the flight proven ATT DSP32C microprocessor. Although this chip family is radiation tolerant, specific provisions have been taken to protect its survival in case of latchup triggered by a high energy cosmic ray event. The principal function of the DSP is a photon formatting task that takes random photoevents in their wedge-strip format and optionally converts them into event (x,y) coordinates using full 32-bit arithmetic in order to avoid introducing computational artifacts into the accumulated images. Each event is flagged with anticoincidence shield status and pulse-amplitude information, and folded into a data stream coordinated with filter position and timing events and information. The DSP executes data communications tasks concurrently with the photon formatting. Data are transferred to and from the spacecraft bus in a high-speed block format. During orbital operations the DSP is continuously available to receive a command block, or to dispatch a data block to the on-board data storage system.

3. PERFORMANCE

The performance of the UCB Spectrometer and its components were measured in the EUV calibration facilities at the Space Sciences Lab. The filters' transmission were measured and the grating and detector efficiency measured. The entire spectrometer system was also tested for end-to-end throughput. The detector pulse-height response, flat-field response and noise was measured. The low-noise detector background was found to be 0.01 counts/sec/cm² at a pressure of 10⁻⁶ torr, a factor of 5 lower than the best MCP's flow by our group in the past twenty-five years. Spectral resolution performance, imaging properties and field-of-view were measured on the full instrument using pencil-beams stepped over input angle and position.

We have incorporated the calibration measurements into a calculation of the ultimate sensitivity of the UCB spectrometer to an EUV emission line. In Fig. 3 we compare the calculated sensitivity for the UCB spectrometer for 100 hrs and 1000 hrs of observing time with the best upper limits available in the instrument bandpass. Two distinct models of interstellar line emission are also shown. One model assumes collisional ionization equilibrium, using the emissivities of Monsignori-Fossi & Landini²⁰ and the emission measure from Bowyer et al.²¹. The other model is the delayed recombination model of Breitschwerdt & Schmutzler^{1, 22} whose intensity fits the 0.25 keV soft X-ray background at high galactic latitudes and for which we have assumed attenuation due to the ISM in local cloud of 5×10^{17} ²³. The line from decaying neutrinos is from Sciama³, and the airglow lines are from Chakrabarti et al.²⁴.

In Table 2, we summarize the resolution of instruments which have been, or will soon be used to study the character of the diffuse EUV and soft X-ray background. The UCB instrument has substantial capabilities both in absolute terms and in comparison with these other instruments and, together with the long mission life of *Lewis*, promises to significantly increase our understanding of the Galaxy.

Table 1. Key Instrument Parameters

Bandpass:	500–1100 Å
Field of view:	26° × 8°
Filters:	None, Opaque, 1000 Å Al, MgF ₂
Slit:	0.15 × 60 mm
Grating:	8 cm diameter 18 cm focal length holographically ruled 2460 lines mm ⁻¹
Grating Substrate:	Electroless nickel on aluminum
Grating Figure:	Ellipse of rotation Semi-major axis 242.87 mm, parallel to ruling Semi-minor axes 176.17 mm
Grating overcoating:	silicon carbide
Detector:	Galileo low-noise MCP, 80:1 L/D, 10 μm pores with anti-coincidence guard
Detector photocathode:	chemical treatment
Detector encoding:	Wedge and strip
Spectrograph Size:	40 × 40 × 13 cm
Spectrograph Weight:	10 kg

Table 2. Diffuse Galactic ISM Experiments

	Bandpass	Resolution (E/ΔE)
<i>EUVE</i> ¹¹	190–250 Å	10
<i>EUVE</i>	400–460 Å	10
Los Alamos ⁷	130–190 Å	10
Wisconsin ²⁵	40–80 Å	20
Penn State ²⁶	10–50 Å	40–60
This experiment	550–1050 Å	100–200

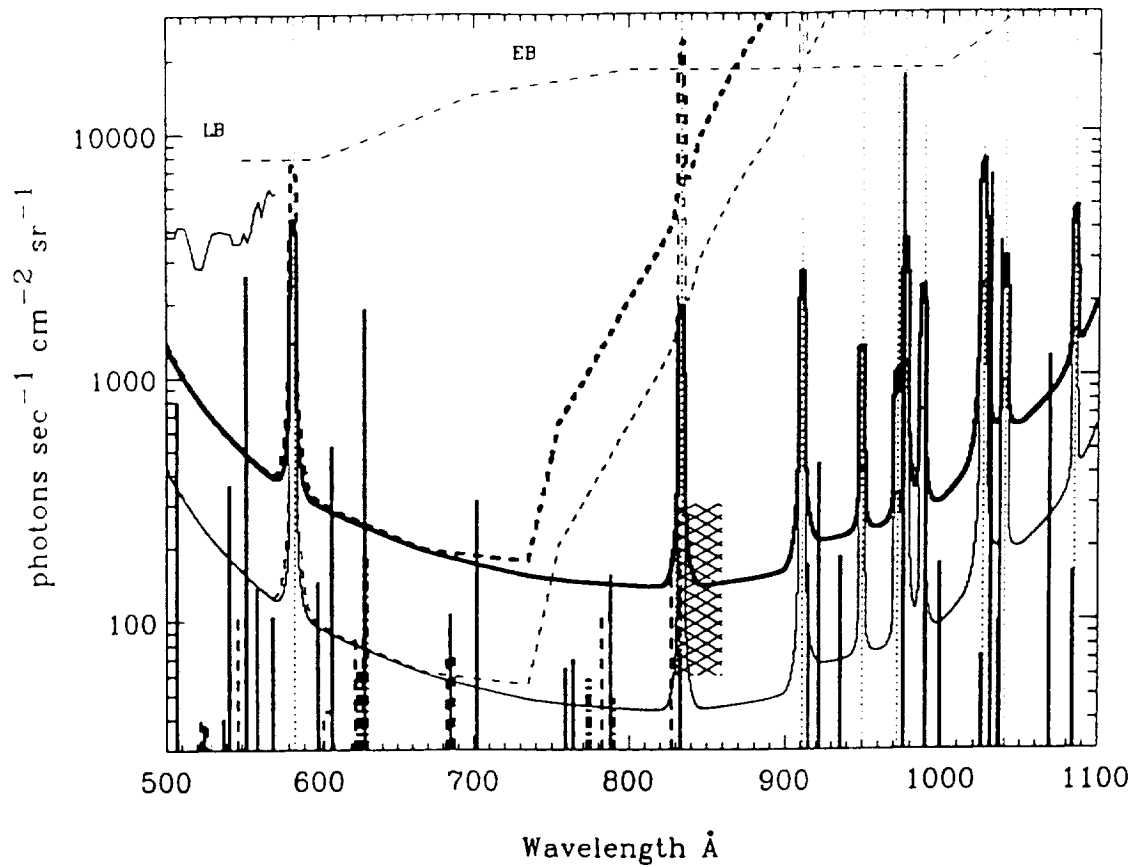


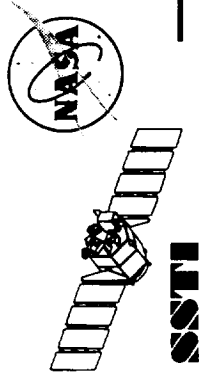
Fig. 3. Existing upper limits to the diffuse EUV cosmic background. LB are the 15 Å resolution limits of Labov and Bowyer. EB are the 30 Å resolution limits derived by Edelman and Bowyer from Voyager data. The curved, horizontal lines are the 3σ measurement flux limits provided by 100 (thick line) and 1000 hrs (thin line) of observation with the UCB spectrometer. The dashed curves correspond to use of the aluminum filter while the solid curve shows similar limits with no filter. The solid vertical lines are the expected ISM emission from a steady-state collisionally ionized plasma. The heavy dashed vertical lines are the intensities from the delayed recombination model of Breitschwerdt and Schmutzler. The fine dotted vertical lines are expected airglow lines. The cross-hatched region shows the range of the emission predicted by Sciama for a halo of radiatively decaying neutrinos.

4. ACKNOWLEDGEMENTS

Ray Chung, Josef Dalcolmo, Chuck Donnelly, Geoff Gaines Rich Hemphill, Sharon Jelinsky, Mike Lampton, Tim Miller, Jerry Penegor, Doug Rogers, Mike Sholl, and Don Zukauckas provided important technical contributions. This work was supported by NASA Grant NGR05-003-450.

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August 9 – Session 7 Experimental Procedures

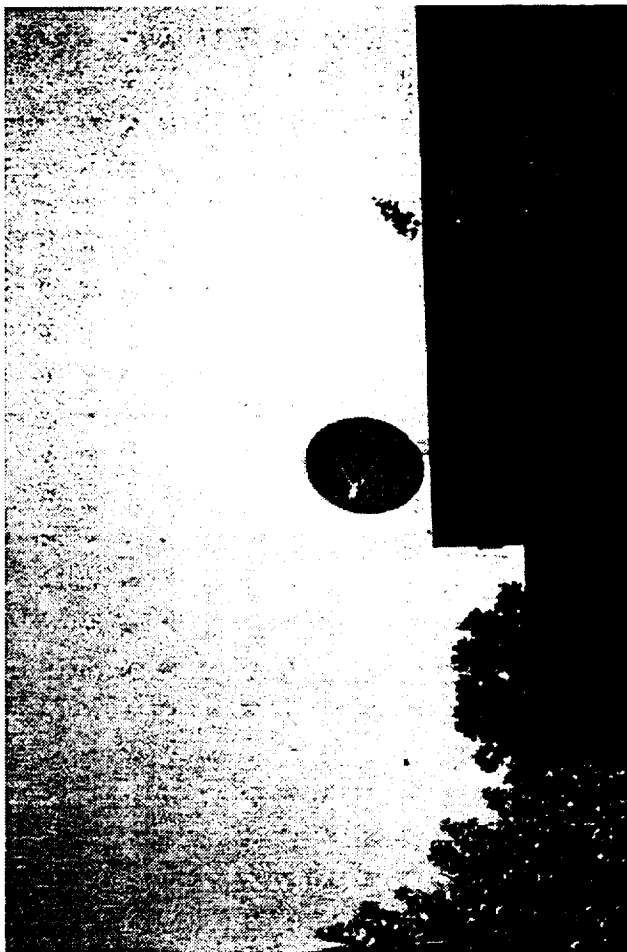


1:00 – 3:30 – E2 Auditorium – Chair: Jay Pearlman

	<u>Speaker</u>	<u>Time</u>
• Planning and Operations	Jim Sarina	1:00-1:45
• Archive Data Processing and Interpretation	Kern Witcher	1:45-2:45
• Mission Tasking Plans	Stephanie Sandor	2:45-3:30



SSTI LEWIS MISSION OPERATIONS



Jim Sarina

SSTI Ground Segment Manager

TRW Spacecraft Operations East

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Chantilly, VA 20151

703 802-1756, 703 802-1861 fax

jsarina@chantilly.trw.com



MISSION OPERATIONS OVERVIEW

- TRW DOES ALL MISSION OPERATIONS ACTIVITIES FOR LEWIS FROM A DEDICATED GROUND STATION LOCATED AT CHANTILLY, VIRGINA
- SSTI GROUND STATION
 - Milestones
 - Overview
 - Station Configuration (2)
- SSTI Mission Operations
 - Activities
 - Tools



GROUND STATION MILESTONES

- Jul 1994: Program Start
- Jan 1995: CDR
- Sep 1995: First Equipment Delivery
- Oct 1995: Final Equipment Delivery
- Nov 1995: Ground Station Operational
- Dec 1995: On-Orbit Test (COBE) Successful

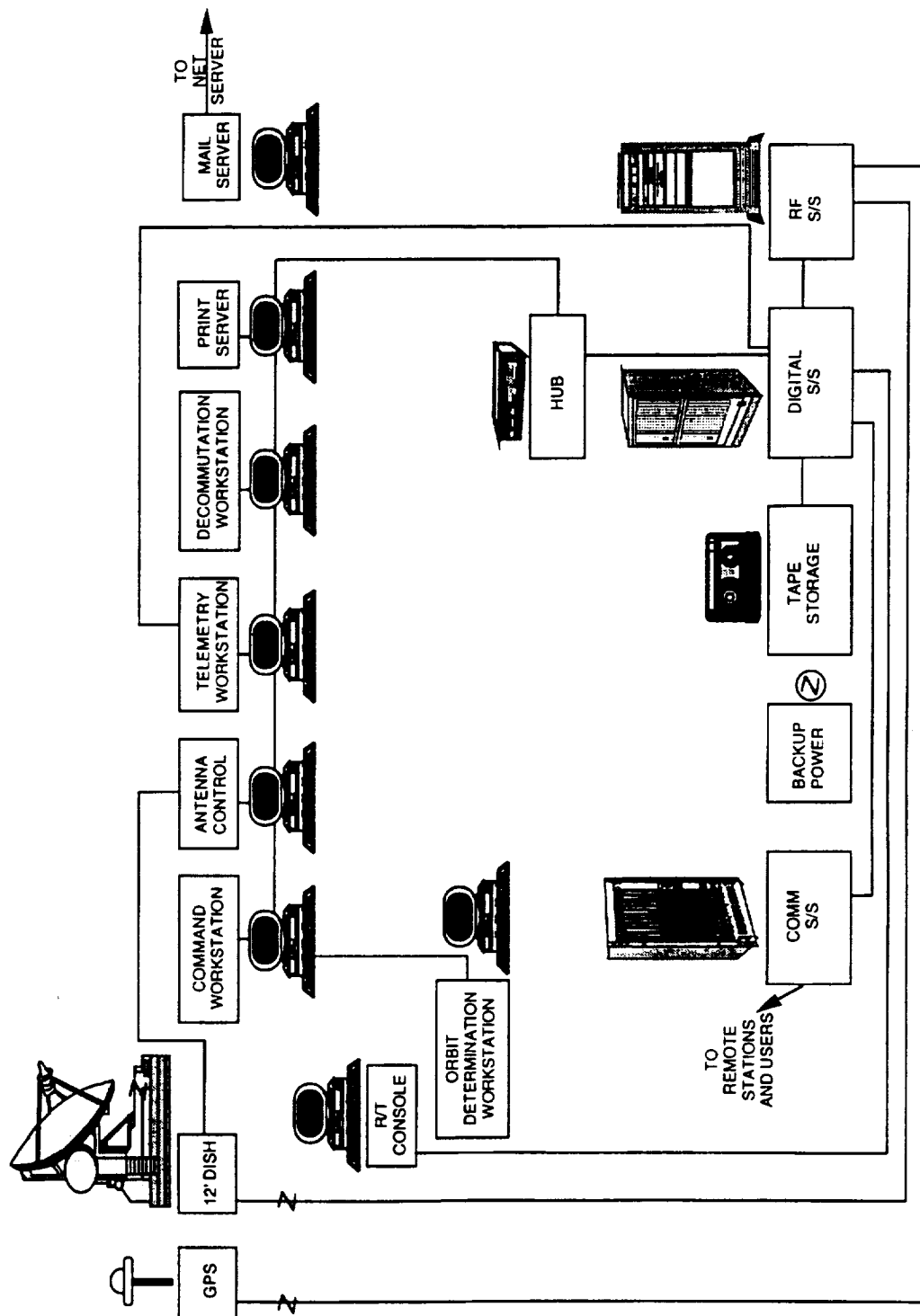
START TO FINISH IN LESS THAN 18 MONTHS!

- Jun 1996: End-to-End Test (Lewis) Successful



GROUND STATION OVERVIEW

Approach and Benefits	Technical Data
• Modular, subcontracted > Best tools for the job	• S-band (2.02 GHz uplink, 2.2-2.3 GHz downlink)
• Fixed-price > Predictable budget	• STDN-compatible
• COTS-based => Low cost, low risk, known schedule	• Autotrack, auto-acquire, search, program track
• Highly networked > Customer connectivity	• 3-axis pedestal eliminates keyhole near zenith
• Integrated product team > High productivity	• 12 foot (3.66 m) reflector • $G/T > 12.1 \text{ db/}^\circ\text{K}$ • EIRP > 43.2 dbW • Data Rate: up to 5 Mbps





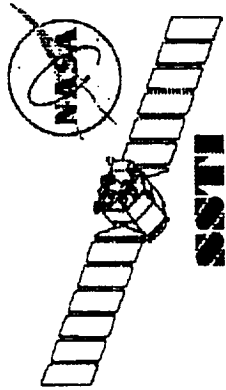
MISSION OPERATIONS ACTIVITIES

- Lewis Mission Operations
 - Integrated Product Team (TRW, Harris, Allied, STI, IS...)
 - Plan all operations from Launch through 5-year life
 - Lead Operations network including 4 remote stations
 - Secure frequency licenses and NASCOM services
 - Command and control spacecraft and 19 experiments
 - Receive, Level 0 process, and forward data to user community
 - Provide all necessary documentation
 - Conduct compatibility and end-to-end tests



MISSION OPERATIONS TOOLS

- Mission Planning and Scheduling (OASYS)
- Orbit Determination and Analysis (OASYS)
- Antenna Control (EMP)
- Maneuver Planning (OASYS)
- Command Generation and Uplink (COMET)
- Telemetry Downlink, Display, Analysis (COMET)
- Archival (8 mm tape)
- Remote Station Interconnectivity (NASCOM)
- High-Speed Data Transfer (dedicated T1 lines)

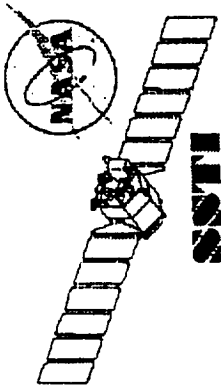


TRW

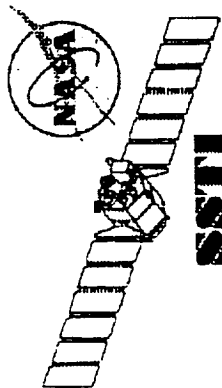
SSTI

Data Archival and Processing System

**Kern Witcher
Jim Sokolowski
Commercial Remote Sensing Program Office
Stennis Space Center
August 9, 1996**



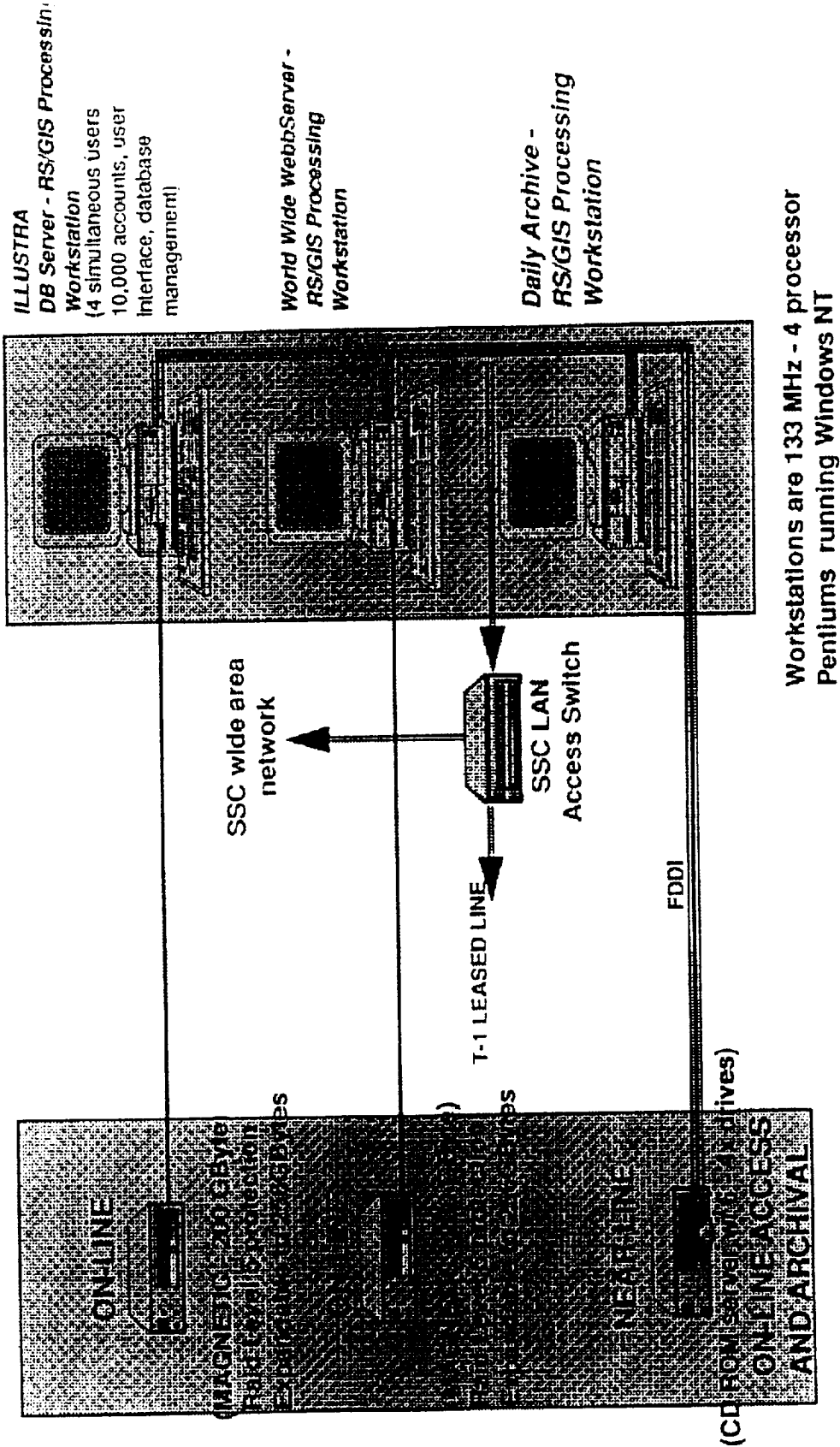
Mission Data Management System

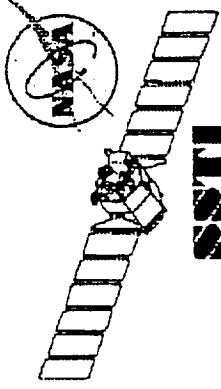


MDMS Current Configuration



SS/T



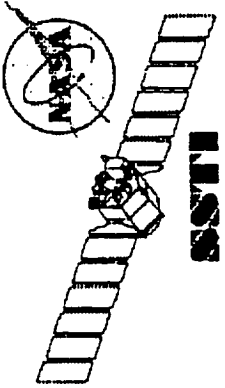


Data Archive System

TRW

• Status

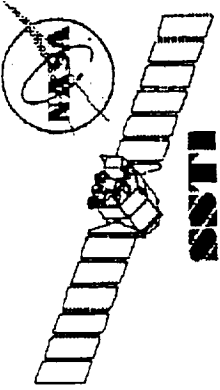
- Data Archive System Operational since September 1995
- System currently has 397 TRWIS-B cubes in archive
- Enhancements in progress
 - » Redesign pages to meet SSC standards
 - » Updating the query interface for all experiments
 - » Automate User entry into the webb server
 - » Enhancing edit and delete user capabilities
 - » Developing additional reports
 - » Enhancing user comment feedback
 - » Enhancing map search capabilities
 - » Enhancing order entry and processing functionality
- Hardware procurement is underway for additional CD-ROM jukeboxes, master copying system and processing workstations
- Final system documentation has begun



TRW



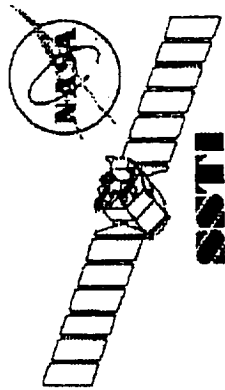
Data Processing System



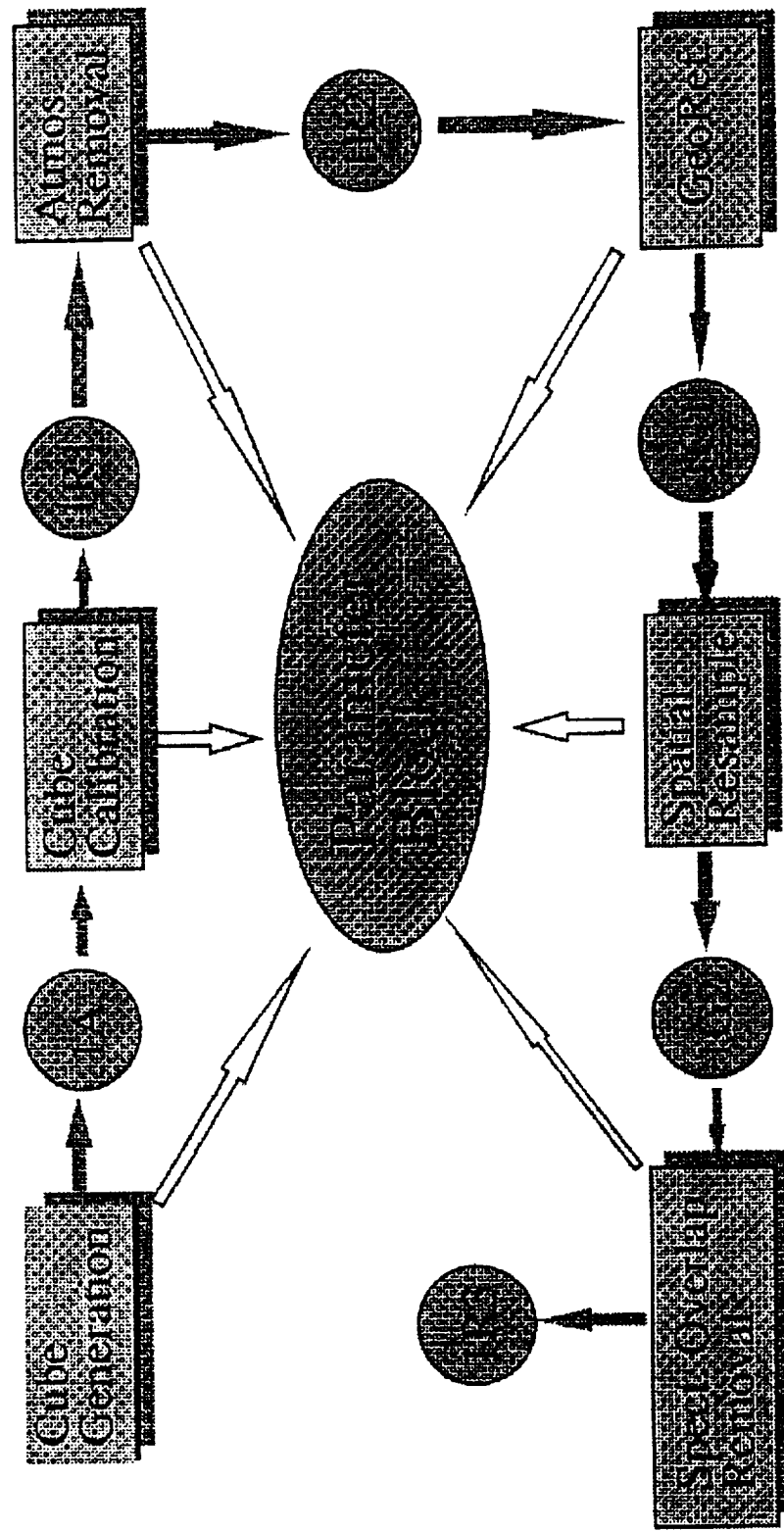
Data Processing System Overview

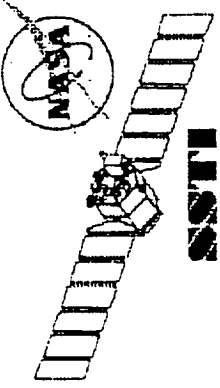


- **Meet the HSI Data Requirements of an Extremely Diverse User Community**
 - Science Applications
 - Commercial Applications
 - Educators
- **Processing of HSI Data Featuring**
 - < 24 Hour Turnaround Time
 - Complete Data Product QA
 - Fully Automated Data Processing
 - Removal of all Significant Data Artifacts
 - Creation of Multiple Data Levels for Various Users
- **DPS Forms the Basis for NASA/CRSP's Remote Sensing Data Processing Technology Testbed**



HSI Data Processing System

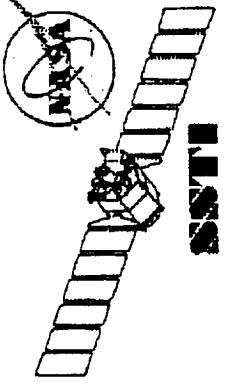




Data Processing Levels



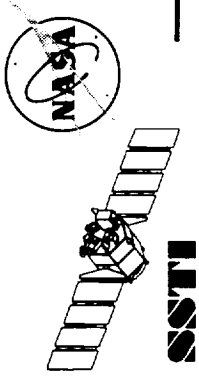
- Level 0 – Individual instrument raw data stream with telemetry redundancies and transmission artifacts removed.
- Level 1A – Image data concatenated into discrete cubes, one per acquisition. Image data is in standard (BIL, BIP) format. All calibration structures, imager headers and metadata structures converted to physical units
- Level 1R1 – Radiometric calibrations are determined and applied to the image data. Image pixel units are radiance at the spacecraft.
- Level 1R2 – Radiometric correction parameters required to correct for all significant atmosphere induced spectral artifacts are determined and applied to the image data. Pixel units are dimensionless reflectance at the Earth's surface.



Data Processing Levels (con't)

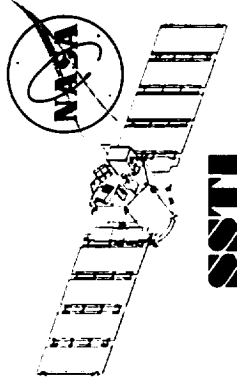


- Level 1G1– Image data for each focal plane are separately georeferenced. That is, the latitude and longitude of the center of each pixel's footprint on and velocity information.
- Level 1G2 – Geometric resampling parameters required to correct for all significant spacecraft induced spatial misregistrations between the focal planes are determined and applied to the image data.
- Level 1R3 –Radiometric correction parameters required to correct for all significant spacecraft induced spectral artifacts are determined and applied to the image data
- Level 2–Full geometric rectification of the image data



Mission Tasking

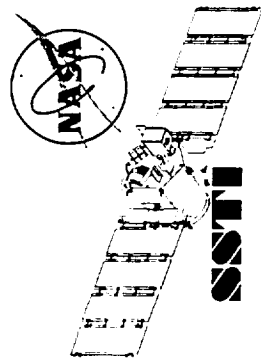
Stephanie Sandor



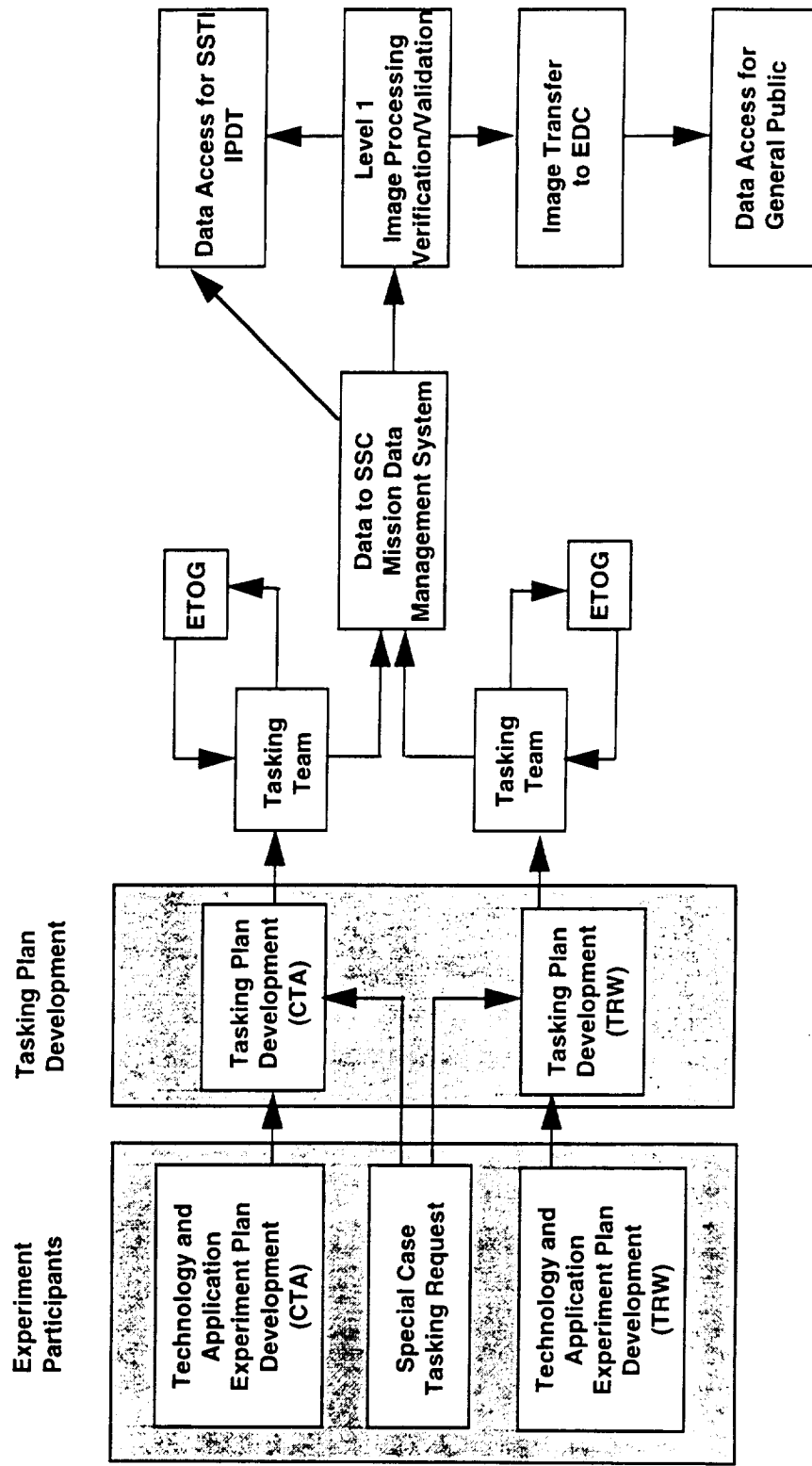
Tasking

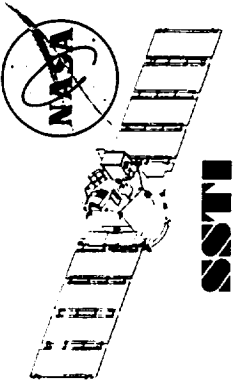


-
- During the first year, the SSTI contractor has responsibility for satellite operations and mission success.
 - Tasking will cover all instruments and technology demonstrations on board the spacecraft including demonstrations which involve uploaded software and processing.
 - During the first year of operation, tasking requests by team members have priority except in the event of a declared presidential national priority or during satellite system checkout, evaluation, maintenance and contingency operations.



Data Flow

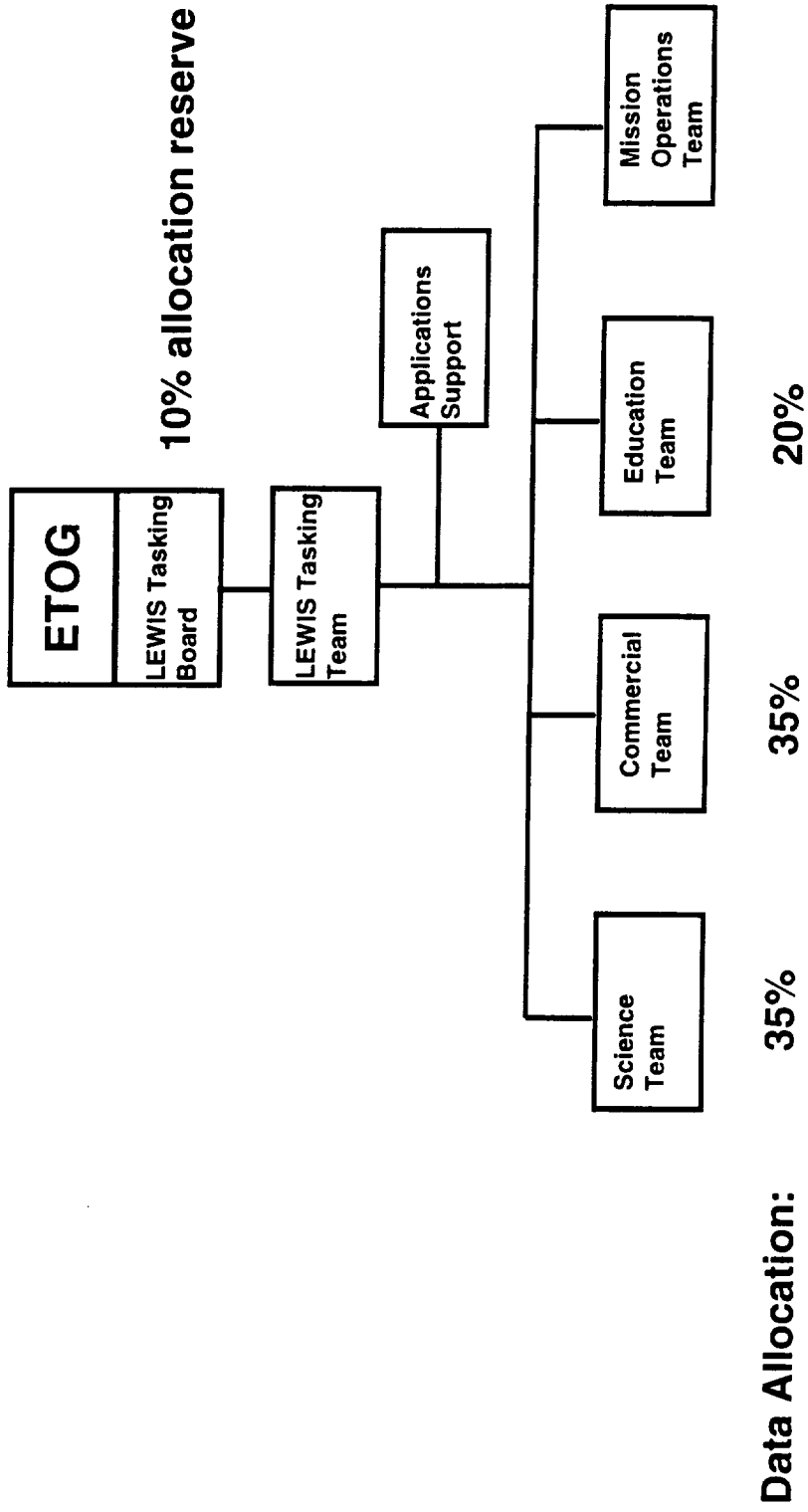


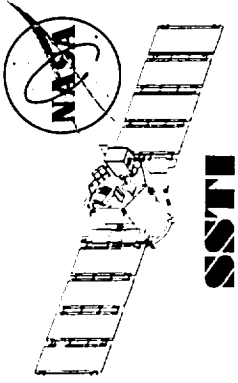


Organization



- TRW has responsibility for the tasking of LEWIS during the first year of operations. Data is allocated as a percentage of the planned 200 images in the first year. The tasking team will have the following organization.

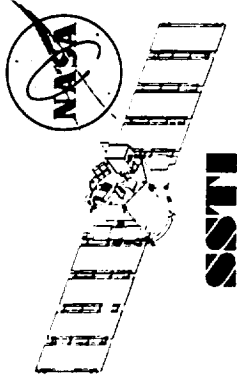




Tasking Process



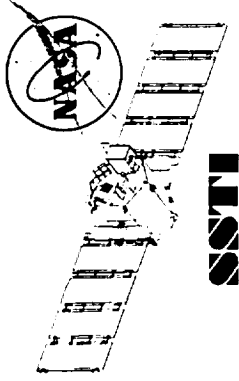
- Tasking requests shall be submitted through the LEWIS Archive or, if the archive is not available, directly to the LEWIS Tasking Team Manager. Non-urgent requests will be collected, summarized weekly for review and sent to the appropriate application team leader for prioritization.
- The prioritized list will be sent to the Mission Operations Team Lead for feasibility validation and scheduling. The Mission Operations Team Lead will return to the tasking team within 4 days a final tasking schedule recommendation for approval by the Tasking team.
- The final schedule will be reviewed and then posted on the Archive; it will be accessible to all users. Individual users will be notified electronically of the approval of their request and the projected date of acquisition.



Archiving

TRW

- Stennis Space Center will archive all Level 0 LEWIS data. HSI data archiving will be done for Level 0, Level 1A, and full Level 1R data and others as deemed desirable by SSC or the LEWIS Team.
 - USGS EDC will archive LEWIS HSI Level 1R2 data and Level 1A data.
 - A backup archive will be provided at TRW on a space available basis. This archive will have the full capability of the Mission Data Management System (MDMS) at SSC
- Data Level Definitions:**
- Level 0: Raw data (with data type, i.e. HSI, LEISA, UCB)
 - Level 1A: Raw data in cube format
 - Level 1R1: Radiometrically corrected image data
 - Level 1R2: Radiometrically corrected for spacecraft induced spectral artifacts



Data Distribution



- Imaging data created by LEWIS will be non exclusive and available to all team members and the general public.
- Data will be distributed either electronically or by recording media to users.
- LEWIS team members and non team members with LEWIS Space Act Agreements will be provided data at no cost through the SSC Archive. Non team members may receive data from the EDC at charges consistent with the data charging policy as allowed by Federal practices.
- There are no restrictions on the use, distribution or resale of LEWIS HSI data. Value-added data may be sold without restriction.
- Data will be withheld from distribution until calibration and instrument operations are verified and tested. Prior to any HSI data release, the data quality must be certified by TRW or its designee.

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